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PORTABLE SOLUTION OF AIR QUALITY IN INDOOR ENVIRONMENTS

Process Life Cycle of indoor air quality

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ABSTRACT

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This research focuses on the portable solutions towards the indoor air quality products that are available in the market. To conduct the research, both quantitative and qualitative methodologies were used. The approach taken was to understand the process life cycle of the indoor air quality products.

The process started with market strategy of such products in both hardware and software industry. Current and future innovations were studied and proposals were drawn after doing gap analysis for different air quality products.

For the process implementation part, work was done in building a prototype of a mobile application that will gather data from the air quality sensors and then use the proposed algorithms to make it into some meaningful data.

The process execution was conducted inside university indoor environment by using the prototype that was built to test the overall indoor air quality of the premises.

Final part of the life cycle was process controlling for which the tests inside the UNIVERSITY INDOOR ENVIRONMENT was done again after adjusting the parameters and using the results from the first round of testing.

Keywords: Portable, air quality, indoor environments

PREFACE

My sincere thanks start from my supervisor Kari Koskinen, who allowed me to use the premises of UNIVERSITY INDOOR ENVIRONMENT and let me follow a thorough research on a young but an important topic in the field of air quality.

My sincere gratitude to all the product owners, famous air quality speakers, representatives from different air quality companies and various ambassadors of different countries who I met in numerous events I attended around the globe.

Than lots of warmth and love to all my friends who not only motivated but helped me in every step of my life. The list is huge but I would like to name every one of them. The list includes Aditya, Hamza, Imaaneh, Jayesh, Madan, Mauno, Ramya, Salman, Shruti, Suvi, Suji, Timo and Vidisha.

Last but not the least my whole family, my sisters who kept on pushing me, my father who secretly misses me and my mother who prayed for me throughout.

Special mention for my late grandma, as “she loved me the most” was her last words to me. May her soul rest in peace.

Tampere, 01.07.2019

Jazib Javed

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1. INTRODUCTION

This thesis work is an effort towards realizing how important indoor air quality is. The thesis focuses on sensing, monitoring and purification research by making prototypes, attending seminars, conferences, talking with companies, research groups and covering state of the art air quality research papers and technologies.

Methodology used for the research were both qualitative and quantitative. Interviews and face to face meetings were done with air quality researchers and professionals as part of qualitative method. Questionnaires were prepared for professionals working inside air quality teams as part of quantitative method.

The work is an end to end effort towards a process life cycle in the field of air quality. It was divided into different sections which included identifying the problem, analyzing the process, prototyping an optimal solution, implementation of the solution, adjusting the results and conclusion.

I started my work with market analysis of the current air quality technologies in both monitoring and purification. The research included state of the art research papers, air quality conferences around the world and high-quality products in the field of indoor air quality.

After researching state of the art products and technologies in the market, I did the gap analysis for two air quality products in the market. I concluded the gap analysis with proposals and a prototype of the proposed innovations. Proposals contained changes for the future generation in the product line and methodologies plus algorithms to be used in the air quality sensor applications.

After making the prototypes, I tested it inside university indoor environment of TUT. The test results included the full in-depth analysis of the indoor air quality parameters inside the university. The tests were conducted twice to get as accurate results as possible.

The data collected through the installed sensors were analyzed to recognize the issues that were in the environment and how the air can be purified to eliminate those issues. The details and specifications of the sensors used was defined clearly to compare how it is better or worse from the other technologies available in the market.

2. THEORETICAL BACKGROUND AND RESEARCH METHODS

The process of indoor air quality includes monitoring of the air quality variables and then purifying it. The most common air pollution variables are temperature, carbon dioxide, humidity, noise level, volatile organic compounds and air pressure. To collect the readings for all six of these, we need good quality sensors. Ideal portable solution should contain these sensors embedded in one small chip.

To get this done, it is important to include a fan to cool the overall temperature of the chip inside the product. Apart from the chip, ability to connect the product to external server and mobile application through Wi-Fi and Bluetooth. A prototype of such product is shown below.

Figure 2.1 *Picture of an air quality sensor*

The device collects the data around its surroundings and sends it to cloud through the Wi-Fi where the user can monitor the readings through an app. Prototype of one such server showing readings looks like this.

The server dashboard shows the live collected data value according to its range with respective to ideal, okay or bad. The green color represents ideal, with orange being okay and red for poor.

Figure 2.2 *Look of a cloud server showing monitored data readings*

As the data gets collected, the app does the machine learning and suggest what needs to be done e.g. a meeting room should only be booked for 1 hour with 8-10 people etc.

Most of the products are designed to be user friendly. Lots of efforts been put in how it looks. The idea of portability is such a key factor among the device manufacturers and designers. Ability to take the device with you anywhere you want, plug it in with your laptop, power outlet or your power bank. For example, if you want to know how your room in Helsinki feels like at the current moment while traveling, the information should be in your hand.

In future, user will also be able to customize the values and reprogram which means the air around you will always be in your control e.g. if the CO2 gets at a value the air conditioner gets on automatically for the period until the CO2 gets at a lower value. All this with this small device. Lot of devices comes with a visual indicator which means it alarms you by changing colors.

Figure 2.3 *Examples of graphs recorded at the cloud server*

When the data is recorded, the dashboard shows the graphs from the collected values like above. Each value is saved and turned into the graph automatically for more analysis.

From the figure, you can clearly see how the graphs are shown and the signal for the respective sensor as well. If the graph showing the last hour data within acceptable range for air quality then it is showing “OK”.

To understand how monitoring of air quality works, I worked on the prototype which included the cloud server dashboard and mobile application that will fetch the data from the devices and send it to the cloud.

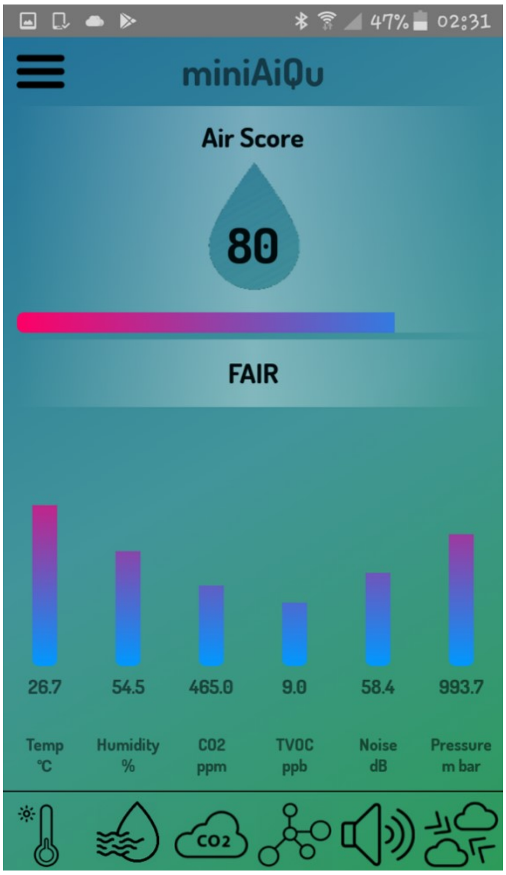


Figure 2.4 *Mobile application prototype main page*

User interface of the prototype was designed for two versions. First interface was for the current android application that collects the data and sends it to the cloud. The other interface was smartly design for the future, considering the color scheme, demand of the future products and its scalability.

Let’s look at the current interface and see how it looks and what it must offer for the users of the product. We start with the main page.

The main page precisely offers four important things, which are as follows:

- Air score.
- Horizontal bar representation of the overall Air score.
- Six vertical bar representation for six different sensors respectively.
- Current value of the sensors in its SI unit.

Main page then allows the user to move to the sensor original page which shows the bar and value in detail with some tip from the analyzed data.

2.1 Methodology behind calculating air quality sensors values

Air score is a number which is calculated through an algorithm and given out of 100. The number close to 0 considered poor and when it reached near hundred it is said to be an ideal number.

That number is a representation of the quality of the indoor air at the present moment. The number keeps changing according to the values of all the six sensors that are chipped in the product.

Air score algorithm is carefully designed by taking an average value from the current range of each sensors. Let’s consider the steps of the algorithm.

1. Each sensor value is recorded at an instance at which the air score is required.
2. Now we have six different values of different sensors.
3. Each sensor is divided into five ranges worst, poor, okay, good, ideal.
4. Five range values are given five fixed values out of 100.
5. Current sensor value is placed into one of the five ranges.
6. Once the sensor is placed into the range, it is now given the fixed value.
7. That fixed value is the same as the range fixed value.
8. All six sensor then follow the same procedure above to get six fixed values.
9. Six fixed values are added and after addition of all the values, it is divided by 6.
10. The resulting value is the overall air score of the indoor environment.
11. The overall score is out of 100, with 0 being the lowest value.
12. For air score value, five ranges are given.
13. Each range represents a word which shows the quality of the air.

14. Worst, Poor, Okay, Fair and Ideal are those words representing the ranges.
15. Then a fixed value is given to that air score.

Let's take an example of air score calculation taking the same random values. We start with the sensor values.

- Temperature = 28.7
- Humidity = 54.5
- CO2 = 675
- TVOC = 9
- Noise = 56.4
- Pressure = 993.7

Now we give ranges to each of the sensors. Following are the six tables showing ranges given and its fixed value. We start with temperature chart.

Table 2.1 *Temperature Chart*

Range Name	Range Values	Range Fixed Number
Worst	>35 & <10	0
Poor	>=10 & <16: >30 & <=35	25
Okay	>=16 & <19: >27 & <=30	60
Fair	>=19 & <21: >24 & <=27	80
Ideal	>=21 & <=24	100

Table 2.2 *Humidity Chart*

Range Name	Range Values	Range Fixed Number
Worst	>=0 & <5: >95 & <=100	0
Poor	>=5 & <15: >80 & <=95	25
Okay	>=16 & <25: >65 & <=80	60
Fair	>=25 & <35: >45 & <=65	80
Ideal	>=35 & <=45	100

Table 2.3 *CO2 Chart*

Range Name	Range Values	Range Fixed Number
Worst	>=2000	0
Poor	>=1500 & <2000: >80 & <=95	25
Okay	>=0 & <250: >1200 & <=1500	60
Fair	>=250 & <400: >1000 & <=1200	80
Ideal	>=400 & <=1000	100

Table 2.4 *TVOC Chart*

Range Name	Range Values	Range Fixed Number
Worst	>=20	0
Poor	>=15 & <20	25
Okay	>=10 & <15	60
Fair	>=7 & <10	80
Ideal	>=0 & <7	100

Table 2.5 *Noise Chart*

Range Name	Range Values	Range Fixed Number
Worst	>=95	0
Poor	>=70 & <95	25
Okay	>=50 & <70	60
Fair	>=30 & <50	80
Ideal	>=0 & <30	100

***Table 2.6** Pressure Chart*

Range Name	Range Values	Range Fixed Number
Worst	<900 & <100	0
Poor	>=900 & <902: >998 & <=100	25
Okay	>=902 & <904: >996 & <=998	60
Fair	>=904 & <910: >990 & <=996	80
Ideal	>=910 & <=990	100

Now we have all the ranges from all the six respective sensors. Now it's time to give the actual sensor value its fixed number from its chart as shown above.

- Temperature fixed number = 60
- Humidity fixed number = 80
- CO2 fixed number = 100
- TVOC fixed number = 80
- Noise fixed number = 60
- Pressure fixed number = 80

After getting all the six fixed values, we add all of them to get accumulated fixed number. Example of accumulated fixed number calculation as follows:

$$\boldsymbol{Accumulated\ fixed\ number = 60 + 80 + 100 + 80 + 60 + 80} \quad (1)$$

From the above equation, the accumulated fixed number is equal to 460.Once we have the accumulated fixed number, now it's time to divide it by 6 to get the air score. Formula for air score and its calculation example;

$$\boldsymbol{Air\ Score = \frac{Accumulated\ fixed\ number}{6} = \frac{460}{6} = 76.67} \quad (2)$$

Now we need to put the air score into its respective range. For that let's consider its chart that shows its range.

Table 2.7 *Air score range quality*

Range Name	Range Values
Worst	>=0 & <25
Poor	>=25 & <50
Okay	>=50 & <70
Fair	>=75 & <85
Ideal	>=85 & <100

According to the above chart, air score comes in the range name between 75 to 85. The air quality is good in that region. Now we give that air score a fixed value which is then shown on the application main page.

Table 2.8 *Air score fixed numbers*

Range Values	Range Fixed Number
>=0 & <25	10
>=25 & <50	30
>=50 & <70	60
>=75 & <85	80
>=85 & <100	100

From the above chart the fixed value given to air score is 80 and its air quality is Good.

Two types of bars are shown on the main page. One is horizontal which represents air score. The other one is vertical which represents individual sensors. Each bar has color ranges in it, which shows the current state of the air quality.

Table 2.9 *Bar color with respective to air quality sign*

Range Color	Air Quality Sign
Red	Alarming or worst
Pink	Poor
Purple	Okay or Neutral
Blue	Good
Sky blue	Ideal

The air score bar starts from red and end at sky blue. So, e.g. if air score shows 80 as above then the bar will end at blue end. As the value goes close to ideal the bar automatically shifts to sky blue range.

The individual sensor bar starts from sky blue and ends at red. So, e.g. if temperature fixed value shows 60 as above then the bar will end at purple as 60 represents okay. As the value goes close to good the bar automatically shifts blue range.

2.2 User Interface designed for the mobile application

As discussed earlier there were two user interface that was designed by me. The idea was that the current interface was designed for already available technology and versions so that user can get used to of the application and how to make sure it is easy enough for them to get accustomed to an indoor air quality application.

The future version was a process of involving futuristic innovations and more colors. Once the users get used to the application then the future version which is more stylish and vibrant should be introduced.

Future version was designed by doing a gap analysis keeping in mind all the innovations and improvements that can be made in the current products available in the market. The improvements to be focused on as follows:

- Specific industry the product is used in
- Changes in the air score with respect to the specific industry
- Analyzed graphs in the application

- Controlling of the sensor values
- Tips according to the outdoor environment

Figure 2.5 *Selection page of a prototype application*

Once the user selects the industry in which the product is involved then the actual main page will open. This main page shows the air score value, six individual sensor values and their respective bars.

The air score now shows the value with respective to the specific industry. This means e.g. in schools the noise level is priority. So, the overall air score takes noise values more seriously and its weightage is more than the other sensor values.

The air score for this version follows the current procedure:

- The industry decides which sensor value or values have more priority
- If the industry has only one sensor as priority then one third of weightage is given to that sensor
- If the industry has two sensors then they are given one third weightage each
- In both cases rest of the weightage is divided equally among the other remaining sensors
- If there is one sensor, priority sensor has 33.33 % and rest have 13.33 % each
- For two sensors, the priority sensors have 33.33 % and rest have 8.33 % each

- Overall air score is formulated by using those weightages in the algorithm.

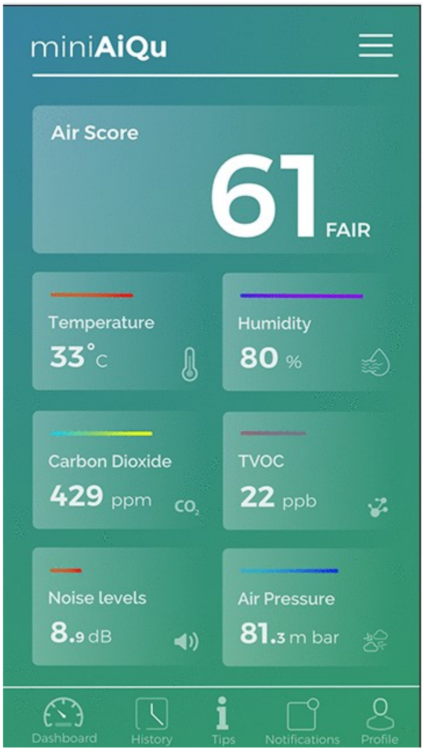


***Figure 2.6** Main data readings*

2.3 Innovation proposed for the indoor air quality market

There is no indoor air quality product in Finland who offers such innovation in one product. Usually different sensors and products are used in different industries to tackle the specific indoor air quality problems. The idea of choosing the indoor environment in the application itself give user full control over the environment he or she is in. Figure 2.9 shows the options available for different industries.

The users have a variety of industries to choose from. Once they have selected the industry then they have customized options to choose from the problems they want the product to focus on as well. The customized problem options are given in the following figure i.e. figure 2.10.

The idea of focusing on the specific area and narrowing it down to the specific problem is a bright idea and bring user happiness to whole new level. There is no product in the market which can do such stuff.

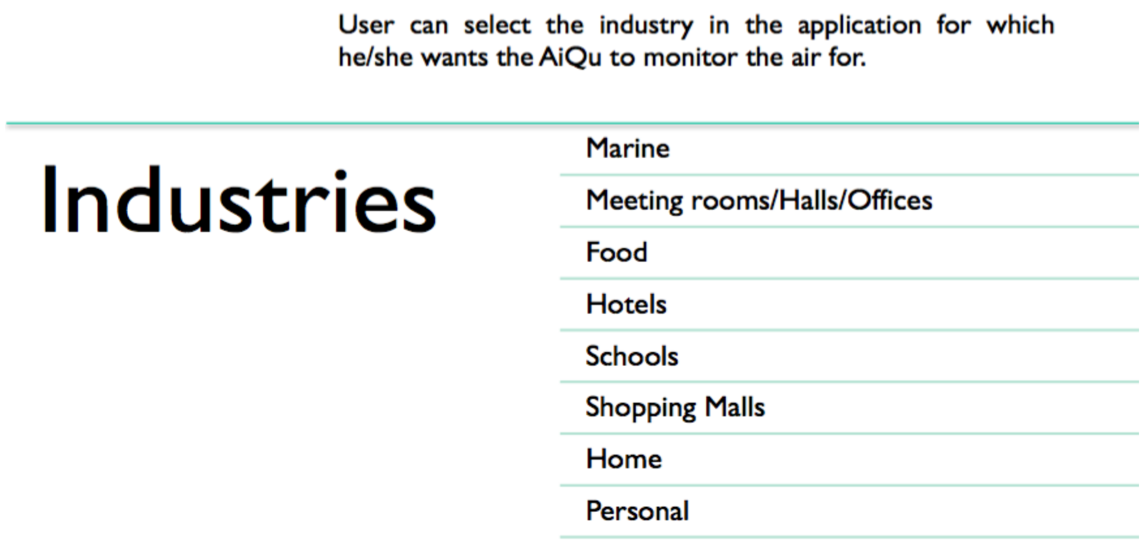


Figure 2.7 *Example of different industries*

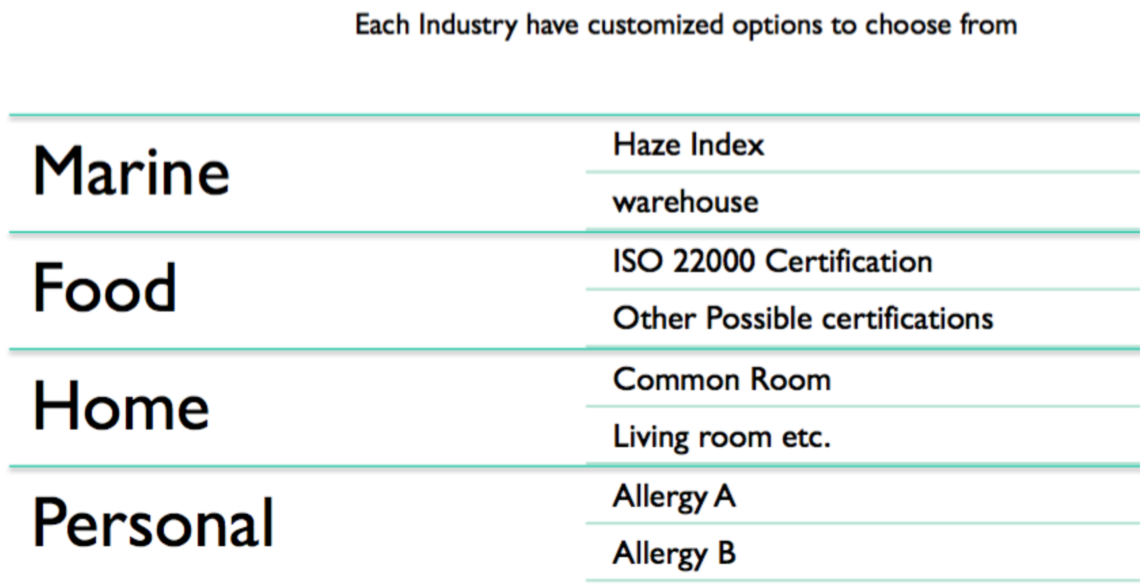


Figure 2.8 *Example of customization options*

The individual sensor page is given a new fresh look aa well. Let's take an example of humidity sensor.

Figure 2.9 *Individual sensor data*

The page shows the current value of the sensor and it gives you an option to see the graph from current, daily, weekly monthly or yearly basis. This page also allows you to set the maximum value at which an alarm will start ringing. User can also set the customized value for a period as well. The application will show whether it is snoozed, completed or overdue.

Once the data is recorded, it is sent to the cloud. The cloud server receives all the data and store it. That data is then turned into graphical form and sent back to the application for the user to see. The data that is stored into the cloud servers are analyzed by the machine and the data analyst to form reports, tips and directions. For the future user interface, the design for the cloud interface is as follows:

As you can see from the figure below, the user has the option to either send the data to the cloud or not. It gives user full control over his or her data. Sometimes users do not want to share their data or for some reason wants to hide a data from a specific period. In the future application, the application user will have the option to send to the data to cloud when they want.

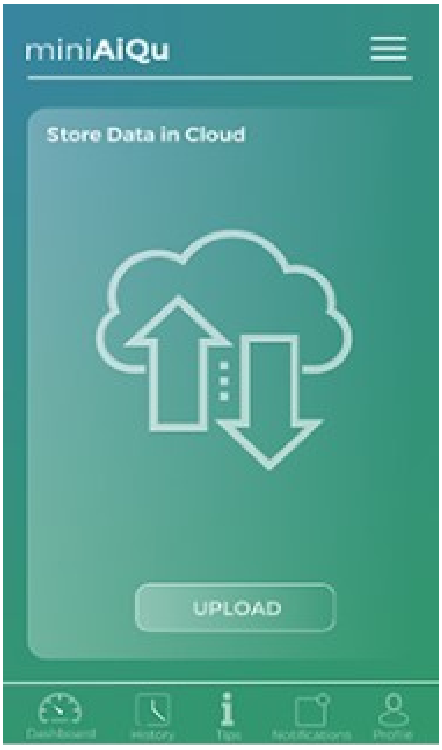


Figure 2.10 *Cloud option interface*

2.3.1 Features included in the Gap analysis

Following are the distinct features that sets the proposed solution apart from other indoor air quality products.

- Visual Indicator
- Design
- More sensors in one small chip
- Battery powered
- Customized for different places and industry
- ISO certifications

Visual indicator is one of the new innovative features that can be integrated in air quality sensor devices. The idea to visually alarm or indicate the current level of indoor air is visually appealing. Colors that can be used to indicate are red, orange, blue and green with red being worse and green being the best.

Many monitoring products have included this feature but there is hardly any product in the market which is working in the domain of air quality has that feature. So, this feature surely makes this product unique.

***Figure 2.11** Prototype of a visual indication*

Design of the prototype product shown above considered few things which were important as per its vision. It must be portable, small but conveniently designed to have all the sensors in it, place for the USB-cable to be attached, cover should have holes for the air to pass through.

Current version did not have cover on both sides. So, new designs were made for the version 2. Following are some of its designs for different parts of the product.

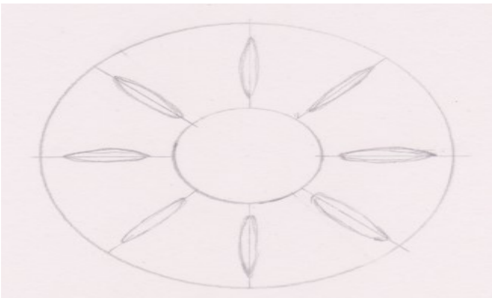


***Figure 2.12a** Design sketch of top look*

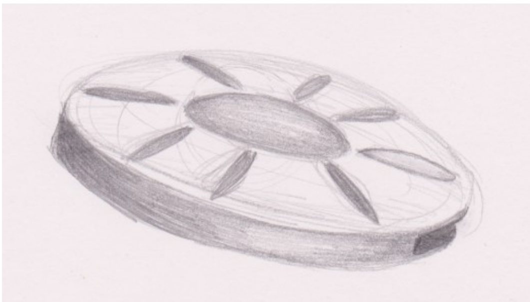


***Figure 2.12b** Angled view of top design*

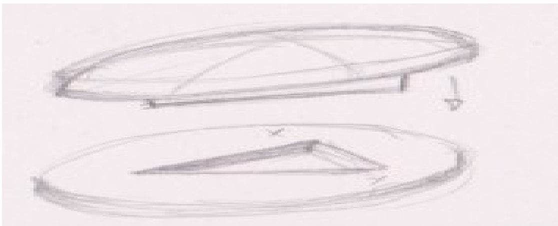


***Figure 2.12c** Sketch design of side on view*

3. TECHNOLOGY IN INDOOR AIR PURIFICATION

The purification technology specializes in the way indoor air quality is improved by removing air impurities. The technology includes a process cycle which includes the filtration process, its purification, distribution and charging.

Figure 3.1 *Example look of a top-quality purifier from Finland* ***[2]***

3.1 Filtration Process involved in air purification

There are mainly two ways of filtration i.e. mechanical and electrostatic. A modern revolutionized filtration technology combines both mechanical and electrostatic filtration which removes harmful particles and gaseous pollutants with high efficiency.

Mechanical filtration gives:

- high volume of flow
- high efficiency rate
- less noise

Electrostatic filtration gives:

- high flow capacity
- low energy consumption
- small ozone generation

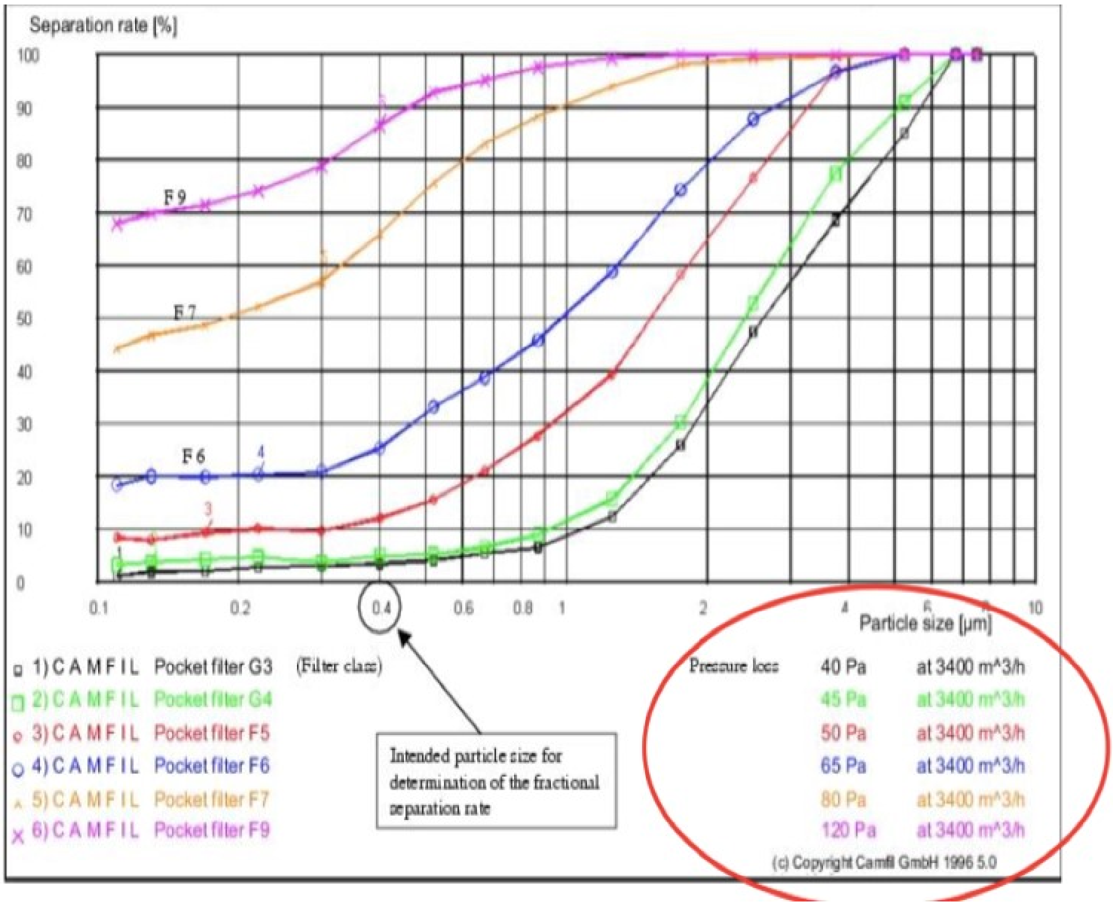


Figure 3.2** Graphs of mechanical filter differences with ranges **[1]

In the mechanical filtration, the purification efficiency and results are dependent on the filter class that you will use. Higher the filter class, better the purification. As you can see from the figure that as the filter class increases, so does its pressure loss.

During the electrostatic filtration first, the impure gas is sucked into the purifier. The air that is sucked in contains impurities such as VOC's, smoke, harmful particles etc. Those particles are given a charge after which it is passed through the metal plates.

Once they are passed through that metal plates then those impure particles are hit at different angles and stick to the metal plates. The particles are negatively charged and metal plates are positively charged.

As the impurities get attached to the plates, the remaining air is sent out to the environment which is free from the harmful particles.

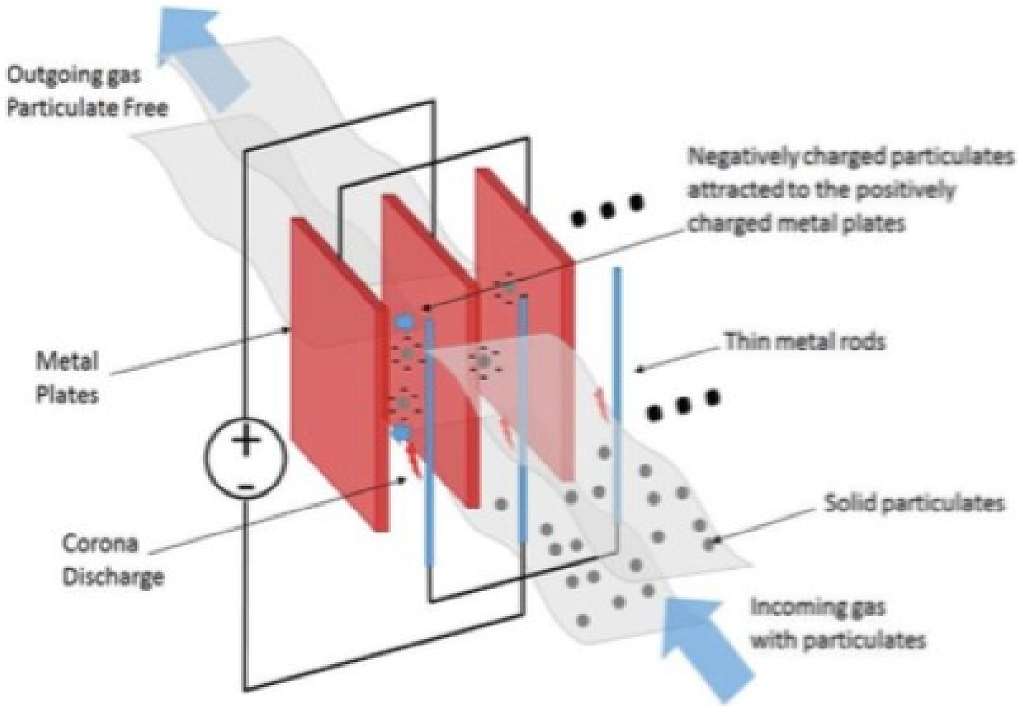


Figure 3.3 *Electrical purification explained through figure* ***[1] [2]***

Example of Genano purifier which uses electrostatic filtration:

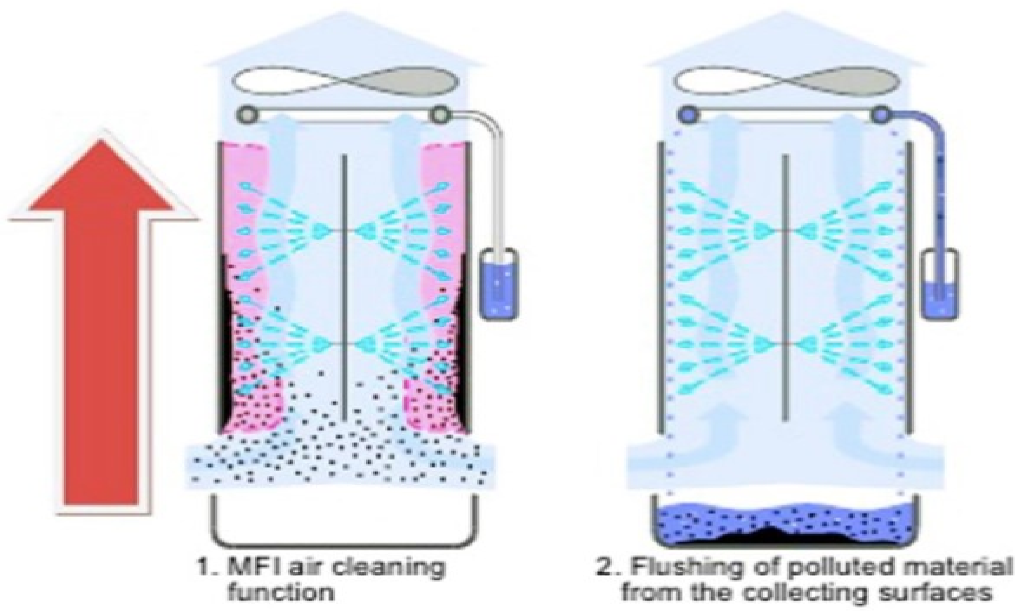


Figure 3.4 *Genano purification explained through figure* ***[3] [4]***

This example is from one of the leading air purifiers. They use the electrical filtration through ionization of particles as described earlier in the previous figure. The air is circulated repeatedly to remove the impurities and to achieve the high efficiency level.

3.2 Innovated Filtration Technology

Mechanical filter whose filtration efficiency is enhanced by electrically charging the particles before they hit the filters.

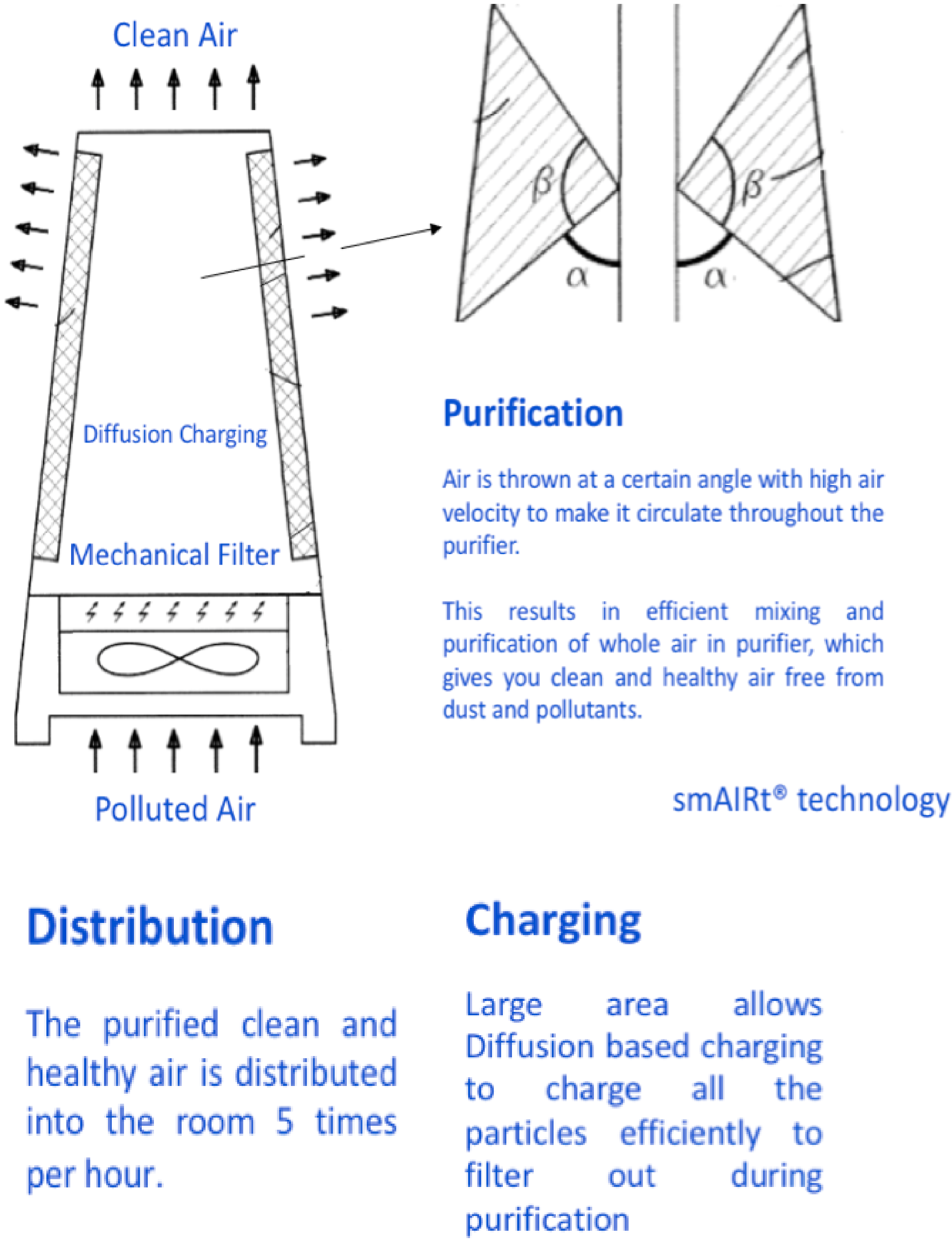


Figure 3.5 *Explanation of air filtration*

3.2.1 Advantages of new filtration technologies

Advantages of revolutionized filtration technology over mechanical filtration:

- Lower pressure drops with same collection efficiency
- Higher volumetric flow
- Higher clean air delivery rate (CADR)
- Less noise

Advantage of revolutionized filtration over Electrostatic filtration:

- Higher flow capacity
- Lower charging voltage
- Smaller ozone generation rate

	New	Mechanical	Electrical
High Clean Air Delivery Rate (CADR) for particles	●		
High Clean Air Delivery Rate (CADR) for VOC's	●		
Efficient filtration of various particle sizes	●	●	
Removes mold, allergens, bacteria, viruses, smokes and smells	●	●	
Silent in use	●		●
No ozone	●	●	
Low maintenance	●		
Energy efficient	●		●

Figure 3.6 *Showing comparison of new technology with other filtration options*

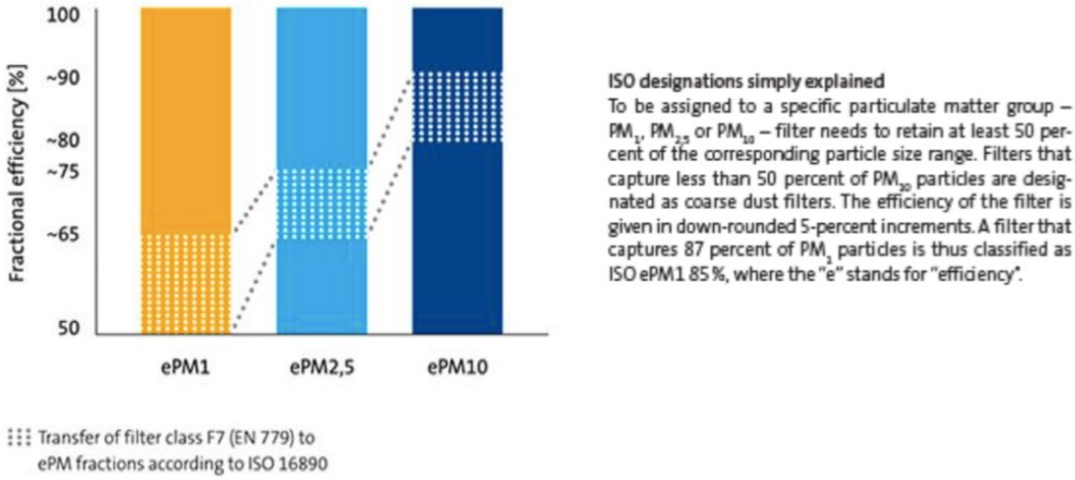


Figure 3.7 *Different types of ISO standards for particle filtration* ***[4]***

In every indoor air quality sensor product, different types of sensors are infused in such a way to get the data from the environment. Those sensors to be used commercially or to be sold must be ISO certified.

There are different size ranges for the particles. The PM in the figure stands for particulate matter. Three different particulate matter groups are shown. In the figure 3.7, e stands for efficiency.

In revolutionized filtration technology, smart sensors PM2.5 standard is in use. The fractional efficiency of that group can be seen from the figure.

EN 779:2012	EN ISO 16890 – RANGE OF ACTUAL MEASURED AVERAGE EFFICIENCIES		
FILTER CLASS	ePM_1	$ePM_{2,5}$	ePM_{10}
M5	5–35%	10–45%	40–70%
M6	10–40%	20–50%	60–80%
F7	40–65%	65–75%	80–90%
F8	65–90%	75–95%	90–100%
F9	80–90%	85–95%	90–100%

If we would classify SmAIRt purifier according to the new standard, it would be marked as ePM1 95, meaning that the purifier filters (in a single pass through it) more than 95% of particles between 0.3 – 1 µm. PM1 is the most challenging class.

Figure 3.8 *Comparison of different ISO standard filters* ***[4]***

3.3 Specifications of proposed innovated Indoor Air Purifier

To understand the purification process of an indoor air quality, a gap analysis was performed of a purifier which uses the same revolutionized filtration technology as explained in the previous chapter.

Purifier used in the analysis comes with the smAIRt® technology which give you the high clean air delivery rate (CADR) with maximum air flow and low noise that purifies the air around you in the best possible manner.

A revolutionized SmAIRt® technology that combines mechanical and electrostatic filtration which removes harmful particles and gaseous pollutants with high efficiency.

Room Size(max)	$50m^2$	$100m^2$
Room Height (average)	2.4m	2.4m
Clean Air delivery rate (CADR max)	$600m^3$/h	$1200m^3$/h
Energy ratings CADR(max) / power	4	6.7
Air Exchange rate /h	5	5
Filter life	12 months	12 months
Electricity Consumption(max)	150W	180W
Sound level range	30-60 dB(A)	35-65 dB(A)
Weight	45 kg	80 kg
Platform	iOS and Android	
Fan Speed levels	5 levels	
Body Type	Finnish Wood	
Sensors	PM2.5, TVOC, HUMIDITY, Temperature	

Figure 3.9 *Comparison of product technical specifications*

3.4 Calculations for different Specification of air purifier

It is very important to understand the dynamics of the specifications shown in the table. The technical specifications of the purifier give the overall impression of how the purifier will work in an indoor environment. The theoretical values may differ slightly from the actual real-life values but the difference or tolerance is not huge in most of the cases in any purifier.

To start with the purifiers are tested in an environment which is called testing place or chambers. The clean air delivery rate depends on the size of the room, air exchange rate plus the height of the place as well. Let's take an example.

To calculate CADR, the formula used is as follows;

$$\mathbf{CADR} = \text{Room size(m.)} * \text{Room height(m)} * \text{Air exchange rate per hour(h1)} \qquad (3)$$

Example of CADR calculation are as follows;

$$\boldsymbol{CADR} = 50 * 2.4 * 5 = 600mBh \qquad (4)$$

In the equation above, the air exchange rate is the amount of times the purifier filters the air inside the room. So, the bad air is replaced with pure and clean air 5 times in an hour.

As per the testing done by the VTT, 1200 CADR which is given by the 1200 Air0 series purifier is the highest by any purifier at that given time when testing was done. It is utmost important to know that this is the core of any purifier. Efficiency means nothing if it is not compared with the CADR. Higher the clean air delivery rate, better the performance of any purifier.

Sound is another important factor in any purifier. It is important that a purifier can provide different levels of purification so that the sound level can be maintained by the user itself or can be automated by using the artificial intelligence.

Sound level of 30 to 65 decibels is usually considered common in the purification world. To compare with the real world, 30 is the noise level we find in most of the libraries. 65, which is the upper limit of the purifier is the noise level of most of the washing machine around the world.

Once we know what the noise level in decibels means, now we can relate it with the fan speed. Logically higher the fan speed, higher the noise. During the testing 4-5 fan level was used.

It is important for the user to have these fan speed otherwise the noise will become a major problem. So, the first fan speed is around 30 dB, which is low just like we can have it in libraries.

The fan speed directly related to the CADR as well. The CADR we calculated is achieved when the fan speed is used at its maximum speed. When lower speed is in use then the performance is lower as well. Ideally the full speed is used before the rush hour of any place or during breaks. Once there are more people the speed can be lowered.

Another important specification is energy ratings. Higher the ratings, of course better it is. The question here to answer is what is energy ratings and how it is calculated. To understand this, we need to know two important factors. One is the CADR which we already know. Second is the electricity consumption.

Electricity consumption is the amount of electricity a purifier uses when it is turned on. Let’s take an example of the 1200 series which uses 180W. W here stands for power unit watt.

So, in a nutshell the energy ratings give an idea how efficient a purifier is in terms of energy being used when compared with the output efficiency of its CADR. So, ideally the CADR must go high and energy consumption must go low for the energy ratings to be better.

Let’s look at the equation of how energy ratings are taken;

$$\boldsymbol{Energy\ ratings} = \frac{CADR}{Electricity\ Consumption\ (\mathrm{max})} \tag{5}$$

Calculation of energy rating example

$$\boldsymbol{Energy\ ratings} = \frac{1200}{180} = 6.6667 = 6.7\,\frac{m^3}{Wh} \tag{6}$$

The energy rating is rounded off to nearest 10 i.e. 6.7 in this example.

Last few things that are important to understand are weight of the product, body type and sensors used.

Weight of the product plays an important part of where these purifiers can be fit in. When we talk about the weight then its body type must be considered as well. Once we know both then we can figure out the color scheme of the product.

This product allows its users to fully customize the color of their purifier which is one of its kind.

Last but not the least, what kind of sensors are used to achieve indoor air quality. Every smart purifier uses a sensor product to compare the reading of the indoor space that has been purified. We will talk about the sensor unit used with these series separately.

3.5 Filters used in proposed filtration technology

Filter specs are completely different from the purification specs but they both are related to each other.

As filtration is a part of the purification process, kind of filter used and its efficiency demonstrates the overall efficiency of the purifier as well. When we are using the mechanical filtration, the type of filter becomes increasingly important as we discussed in the section of mechanical filtration above.

The technical specification of the filter used in Air0 is as follows;

Filter media tells us the series of any filter used. Most of the times when only mechanical filtration is used then the filter capture and filter pressure drop is the same. F9 is the highest capture that can be used. So, higher filter capture means the efficiency is higher. The backdrop of using higher series is that pressure drop is higher as well which means higher noise.

In this product, the unique thing is its dual technology which uses mechanical filtration to enhance the CADR by doing electrical filtration as well. So even though the F9 filter capture is used, the filter pressure drops noticed is of F7.

F9 pressure drop is 80 pascals (Pa) and F7 pressure drop is 120 pascals (Pa)

Number of filters that are used increases the power of filtration. More and more air can be filtered in one exchange. Five filters are used in this product.

Summary of what benefits these technical specifications brings to the product, can be seen in the figure below.

Filter media	Modified Flow2Save®	
Filter Capture	F9	F9
Filter Pressure Drop	F7	F7
Number of Filters	5	5

Figure 3.10 *Calculation of energy rating example* ***[1]***

We have till now fully understood how the purification works, what are the technical specifications of the product and what filter are used in the product. Let's now compare the life cycle and price of different purification models. It has been put in figure 3.15 to simplify its meaning.

As we can see Hepa purifiers which uses mechanical filtration are the cheapest ones to buy but their maintenance cost is the highest.

On the other hand, electrical purifiers have the highest initial cost as it is extremely hard to design them for commercial use, but they hardly have any maintenance cost.

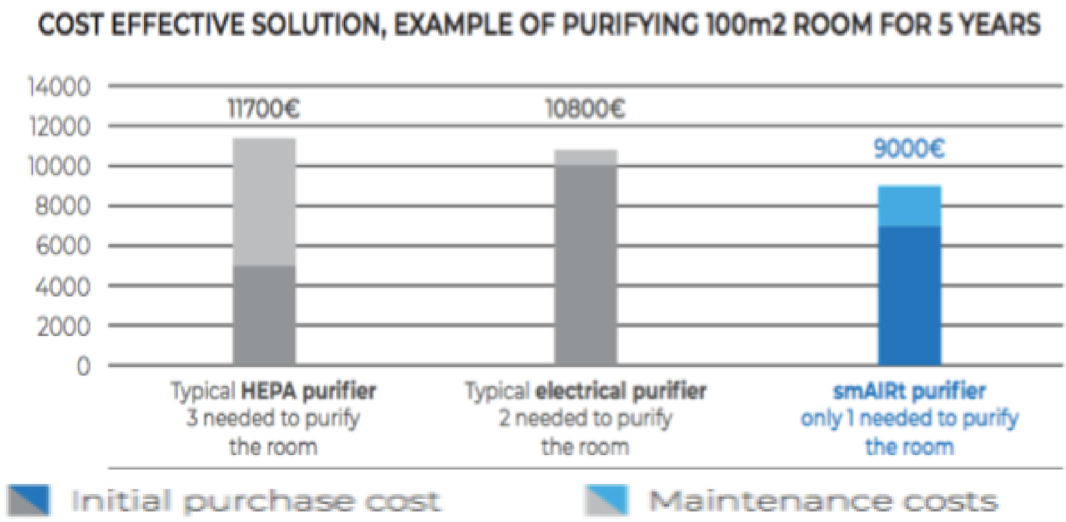


Figure 3.11 *Price comparison with different type of purifiers* ***[2] [5]***

Revolutionized filtration technology uses both the purification in such a way that their overall cost is lowest when we compared all types of purifiers for a longer time. So, neither initial cost or the maintenance cost is lowest but it has the lowest overall cost for five years or more.

Advantages of the proposed technology over other purifiers after gap analysis:

1. High CADR, which means very efficient production of clean-air space
2. High flow, which means efficient mixing and purification of whole space – not just short-circuiting air around the purifier
3. Very large filter area which means long change interval
4. Very low ozone (O3) production which decreases O3 concentration in the space
5. Active carbon impregnated to filter media, ensuring complete O3 capture at all times
6. Quiet, especially below maximum fan speed
7. Low maintenance cost (when calculated for filter price/maximum loading)
8. Special filter media (Ahlstrom Flow2Save®); F9 filter capture with F7 filter pressure drop + high loading capacity due to efficient use of filter depth (i.e. particles are captured also inside the filter cloth, not only on the surface)
9. Diffusion based particle charging with high residence time for charging which is very efficient charging of all particles
10. Easy and safe filter changing (both main filter and pre-filter)

3.6 Gaseous Impurities involved in indoor environments

During the gap analysis, the purifiers used comprise an active carbon filter to remove ozone O3 generated by the charger unit. Active carbon may (and probably will) decrease the amount of some gaseous impurities. However, we do not have any evidence or measurement result of that.

Gaseous impurities are geographical (as PM). In mega cities, we have pollutants from traffic (NOx, SOx, O3, COx) which move from outdoors to indoors (as apartments should have negative pressure compared to outdoors). These pollutants are reactive (also with particulate material) and change to other substances, especially when there is energy available (mostly UV-light from the sun).

Nitrogen oxides, NOx: s cannot be captured by activated carbon only, it must be impregnated (with potassium hydroxide, KOH), a technology known for at least 20 years but not in commercial market.

Sulfur oxides, SOx: s are only removed by activated carbon at elevated temperatures (at least 150ºC, preferably 700ºC). Research carried out in active carbon impregnation is inconclusive.

Ozone, O3, is effectively removed by active carbon. As O3 is extremely reactive, probably pure filter without active carbon would remove O3 – but customers “insist” activated carbon with O3 generation.

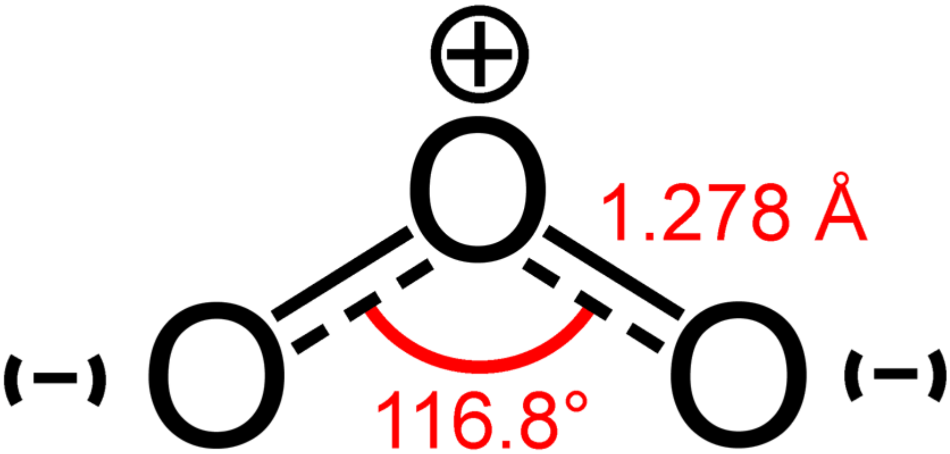


Figure 3.12 *Ozone combination bond* ***[5]***

Carbon oxides, CO and CO2: carbon dioxide, CO2, cannot be captured. Carbon monoxide, CO, can be adsorbed by metal halide impregnated activated carbon, but far easier way is to increase ventilation rate or open a window.

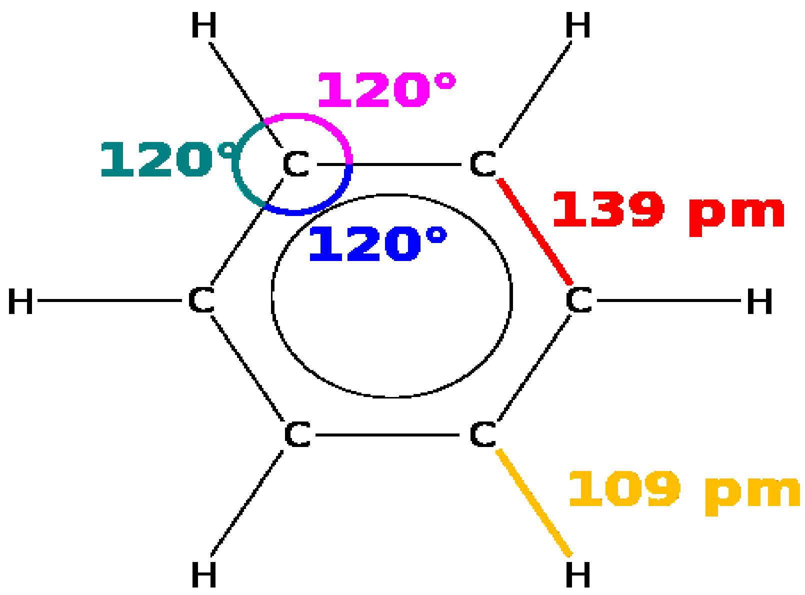
To summarize, vehicle/traffic generated gaseous impurities cannot be reduced by an air purifier, except Ozone, O3.

Indoor air may contain different Volatile Organic Compounds (VOC), like formaldehyde or benzene.

Activated carbon in general captures CH2O which is obviously good for analyzed purifier. However, the core structure of carbon, especially surface chemical composition, greatly influence the formaldehyde adsorption. Thus, we need testing and possible trials (perhaps together with Ahlstrom to find the right type of activated carbon. And test results, obviously.

$CH2O$ monitoring requires a bit different technology than other VOCs and Total VOC (TVOC) detectors may not be able to measure $CH2O$ in a reliable way.

Another important indoor VOC is benzene, $C6H6$.



[6]

Figure 3.13 *Benzene combination bond* ***[6]***

Benzene can be captured with an activated carbon filter – but it also requires special activated carbon and thus any claims on $C6H6$ removal need to show evidence, test results. One important thing in testing is air velocity through activated carbon, to make the system effective with air volume rates of SmAIRt.

In a nutshell, SmAIRt purifier may be good (although not optimal) for removing VOC (or at least formaldehyde and benzene) indoors. But this needs to be tested. One may also consider, if the purifier under consideration should develop a VOC purifier without particle filtration then surely it is top notch.

3.7 Solution proposed to tackle gaseous impurities better

This is currently a very subjective topic, researchers at the production facility have different views and (which needs to be aligned). They do not know what do their customers want in the future.

In the current research and development project within next 6 months they will develop the following:

- Smaller SmAIRt unit (CADR about 600 m3/h)
- PM2.5 monitoring based SmAIRt control
- Cloud-based management of single and multiple purifier systems
- SmAIRt service via the cloud (remote monitoring)
- Daily or weekly SmAIRt profiles (e.g. fan speed change automatically in cooking or sleeping hours)
- Commercial use of SmAIRt data
- Sensors monitoring purifier status
- Total Smart System, capable for Clean Indoor Air warranty

As outdoor air tends to propagate indoors, indoor air quality is finally related to outdoor air quality. Typically, PM2.5 I/0 ratio is determined as follows:

$$\text{PM2.5 input output ratio} = 0.2\left(\frac{+0.2}{-0.1}\right) \tag{7}$$

This means that if outdoor concentration is 100, getting below 20 requires some extraordinary measures. This may not be technically challenging but economically it will be.

4. AIR QUALITY TESTING IN UNIVERSITY INDOOR ENVIRONMENTS

Last part of the thesis was to carry out testing of sensors in the premises of university indoor environment. For that purpose, 2 different types of sensor devices were chosen. The testing was divided into 2 different phases. The second phase sub divided into 2 rounds as well.

Types of sensors that were used in the testing was as follows:

- Mini AiQu & Vaisala
- Foobot

Phase one focused on following sensor results:

- Temperature
- Humidity
- CO2

Phase 2 was sub divided into two more testing rounds. The idea was to go deep into the analysis and produce as accurate results as possible.

1st period of second phase the following sensor results were analyzed:

- PM2.5
- VOC

During the 2nd period of second phase the above-mentioned sensors were analyzed along with the sensor results from the relative humidity.

The idea was to test the same places in university indoor environment at different times for different air quality sensors to analyze how good an air quality is inside the university indoor environment premises.

For each phase, the data was analyzed and converted into a simple graph for a better and quick understanding. At the end of the analyzes some suggestion have been added to be considered for the better air quality inside the department.

Let's now study the results that were gathered during the testing. For every phase, three different rooms or lobby were chosen for the air quality monitoring.

4.1 Testing including temperature, humidity and CO2 sensors

Phase one was performed with mini aiQu sensor and focus was on temperature, Humidity and CO2. To compare the results of mini aiQu, vaisala sensor were placed as well to check the tolerance between them and how accurate mini aiQu sensors were. The phase one was performed in the main lobby.

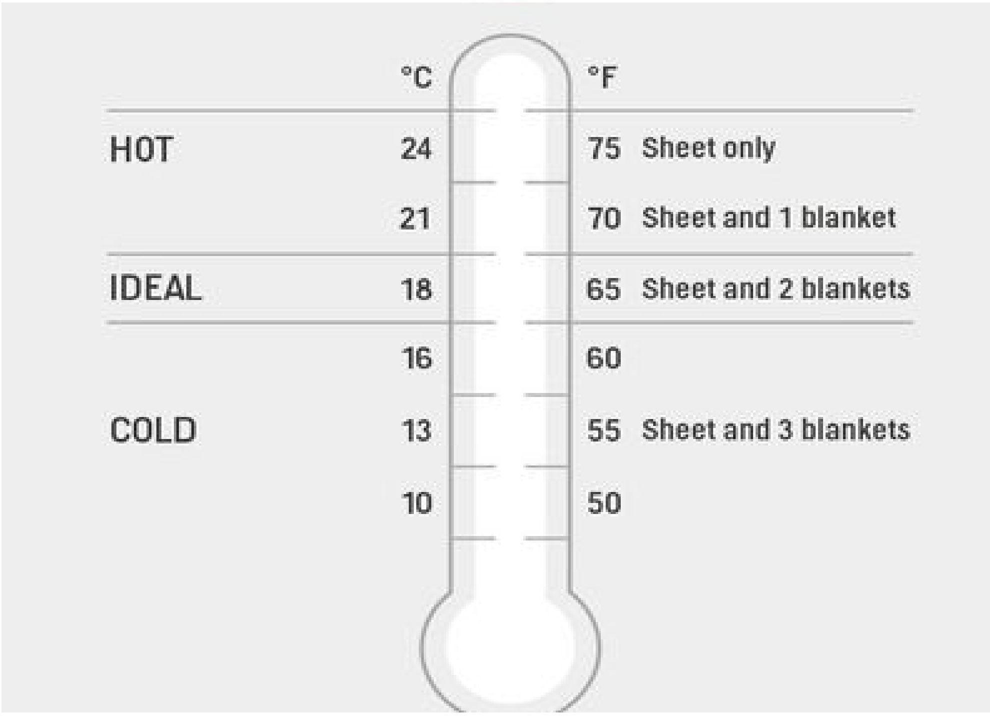


Figure 4.1 *Temperature range explained for air quality comparison*

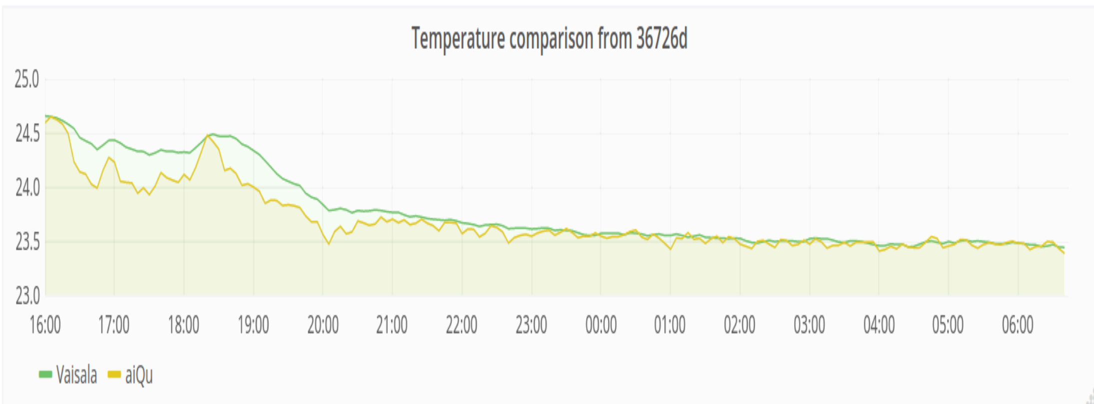


Figure 4.2 *Temperature analysis*

The graph shows that the maximum temperature inside the department recorded which stayed above 24 during the working hours and drops a degree after 6 pm. During night until the morning, it stays around 23.5 consistently.

The graph above shows the average temperature that was recorded compared to Vaisala. Both sensors stayed around 21 degrees and the average tolerance was 0.05 degrees.

To understand relative humidity concept let's look at the figure below to see what each range in relative humidity means with respect to the temperature outside.

Table 4.1 *Humidity range explained for air quality comparison*

Outdoor temperature	**Ideal indoor humidity**
20 to 40 degrees	Not more than 40 %
10 to 20 degrees	Not more than 35 %
0 to10 degrees	Not more than 30 %
-10 to 0 degrees	Not more than 25 %
-20 to -10 degrees	Not more than 20 %

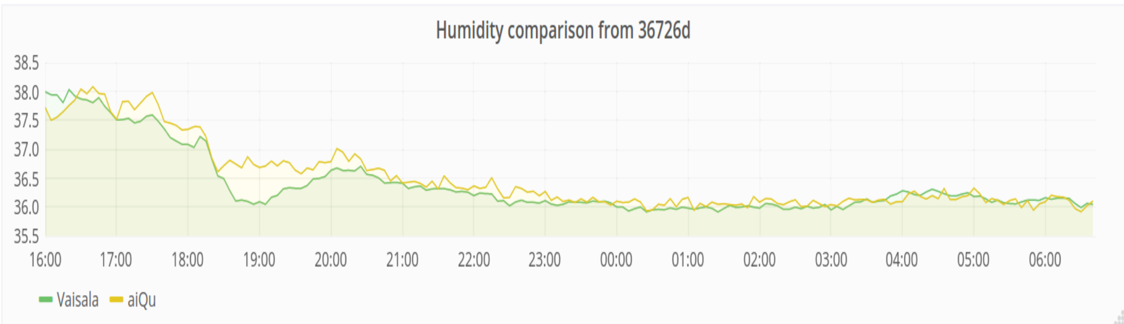


Figure 4.3 *Humidity analysis*

he graph shows that the maximum humidity inside the department recorded which stayed above 37 during the working hours and drops a percentage after 6 pm. During night until the morning, it stays there consistently. As the outside temperature during the testing time was between 10 to 20 degrees, ideal humidity should have been under 35.

The graph above shows the average temperature that was recorded compared to Vaisala. Mini aiQu sensor stayed at 24.87 percent, while Vaisala sensor recorded 24.44. The average tolerance was 0.57 percent.

To understand CO2 concept let's look at the figure below to see the ideal ranges for indoor climate with respect to CO2.

Table 4.2 *CO2 range explained for air quality comparison*

250-350 ppm	Normal background concentration in outdoor ambient air
350-1000 ppm	Concentration typical of occupied indoor spaces
1000-2000 ppm	Complaint of drowsiness and poor air
2000-5000 ppm	Headache, sleepiness, stale and stuffy air
5000 ppm	Workplace exposure limit (as 8-hour TWA) in most jurisdictions
>40,000 ppm	Exposure may lead to permanent brain damage, coma & death

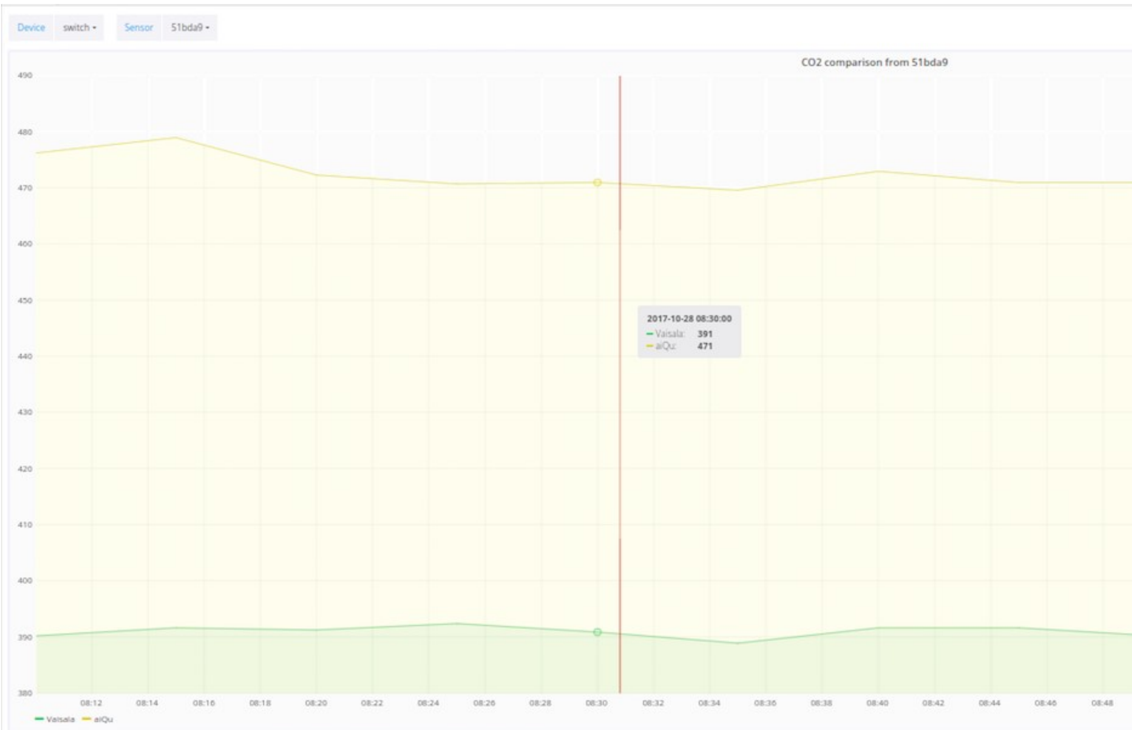


Figure 4.4 *Comparison of CO2 values between mini aiQu vs Vaisala*

From the above figures, we can see that normal range for ideal CO2 is between 250-350 ppm. Ppm stands for parts per million. Average values taken from aiQu and Vaisala sensors were in the range of 350-1000 ppm, which is not bad. Vaisala average value was 391 ppm whereas aiQu recorded 491 ppm. Tolerance between the two sensors were 81 ppm.

4.2 VOC and PM2.5 sensors testing analysis in UNIVERSITY INDOOR ENVIRONMENT

Phase 2 of the testing was sub divided into 2 parts. 3 rooms were chosen for this phase. During this phase, more accurate sensors were used from Foobot. Part 1 was for measuring particles and VOC's. The aim of this phase testing is to give the first view on the measurements carried out in university indoor environment. Following were the items unknown during testing:

- The power level of the product, and if the product has they been continuously on or not.
- The room volumes
- Number of windows/doors in each room and have they been open or close.
- Are there indoor pollution sources (especially particle sources) in the rooms, etc.

Hopefully some of these items can be found out afterwards. A basic problem, however:

- What is the background levels in the rooms without and after purification? In next testing, we can use the timer option to switch purifier on/off to get better test data.

VOCs were measured by Foobot, i.e. non-calibrated sensor which does not follow the ISO 16000-6 measurement standard. Thus, the absolute values of the measurement results must be taken with precaution as they may differ, even heavily from true values. It is, however, very probable that the sensors show the trend right. Each sensor has shown the minimum value of 125 ppb (mg/m3) which stands out. Perhaps this has been set to be the minimum value. To understand meaning of different ranges of VOC's values, let's look at the figure below.

Table 4.3 *VOCs ranges explained for air quality comparison*

Level	Home	Office	Production
Ideal	<200	<200	<500
Good	200-300	200-350	500-700
Acceptable	300-400	350-500	700-1000
Marginal	400-500	500-700	1000-1500
Actionable level	>500	>700	>1500

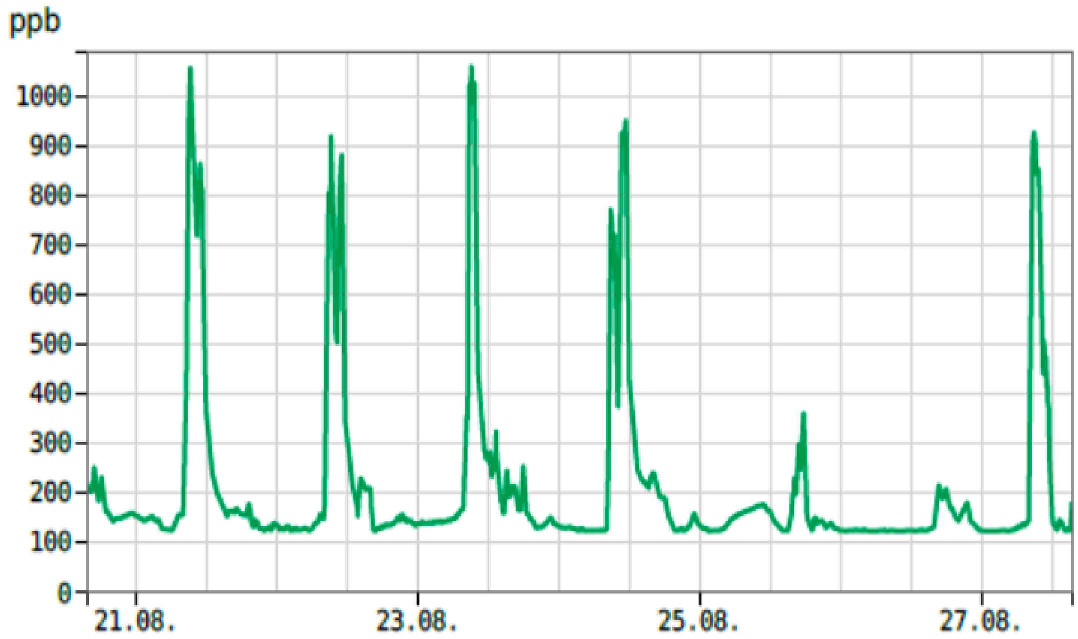


Figure 4.5 *Room 1 VOC graph summary*

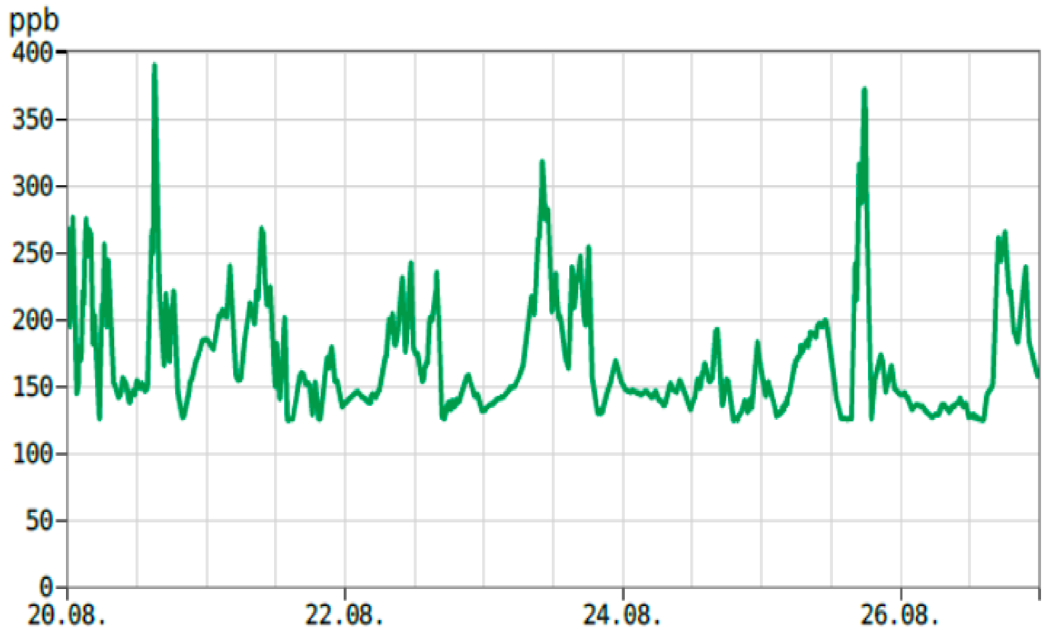


Figure 4.6 *Room 2 VOC graph summary*

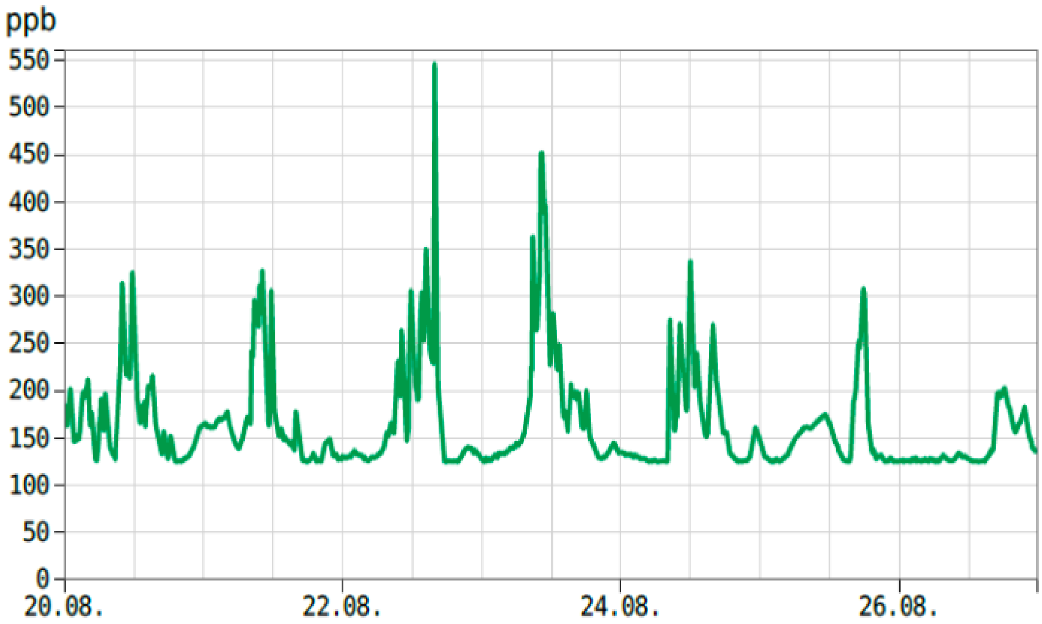


Figure 4.7 *Room 3 VOC graph summary*

It seems that in overall VOC-levels are in a range which does not require actions in room 2. However, one must be careful with this as the sensors are non-calibrated. Due to this reason, it would be wise to study the room more carefully, perhaps using standardized measurement method.

It is necessary to see, if the results are different when other sensors are used. If the standardized method also shows high VOC peak levels, then it will be necessary to clarify which VOC are we talking about. This allows us to optimize the VOC purifier for those specific substances.

Room 1 has clear daily VOC peaks occurring before noon. Those values go above 1000 ppb and that is too high for an indoor lobby. The reason for this should be clarified. As we cannot see such peaks in other areas, the reason is probably an indoor source inside or near the lobby area. Now, the other areas do not need VOC purification, assuming the VOC sensors are" at the range", i.e. not showing far (more than 50% deviation) from the true value. This can only be found out by calibrating the sensors.

In nutshell, the lobby area needs VOC purification after the part 1 testing results. The VOC's during the rush hour of working time goes high.

Ideally it will be nice to put a purifier and do the testing again to compare the results of the lobby air quality.

PM2.5 sensor measures all the smallest of dangerous particles that our naked eye cannot see, but they are extremely harmful for our health.

Let's look at the ranges and what they mean before analyzing the graphs for the results.

Table 4.4 *PM2.5 range chart*

Range	Value
0-9	Ideal
9-11	Good
11 above	Bad

So, now we have 3 ranges of ideal, good and bad which will be used to analyze the current situation of particulate problem in the three rooms chosen inside university indoor environment for its indoor air quality measurement.

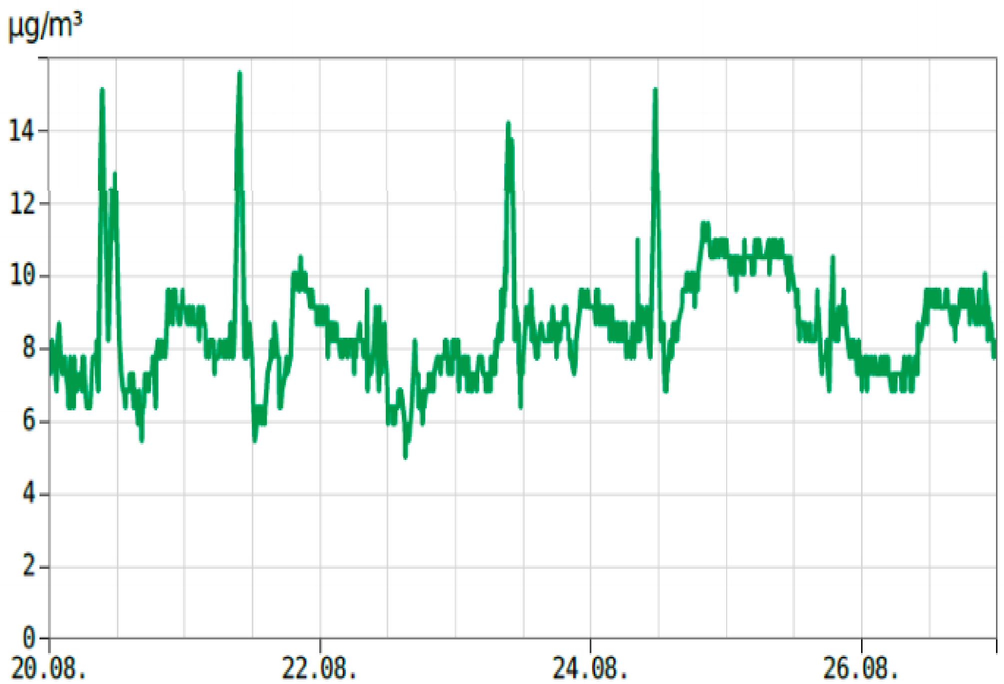


Figure 4.8 *Room 1 PM2.5 graph summary*

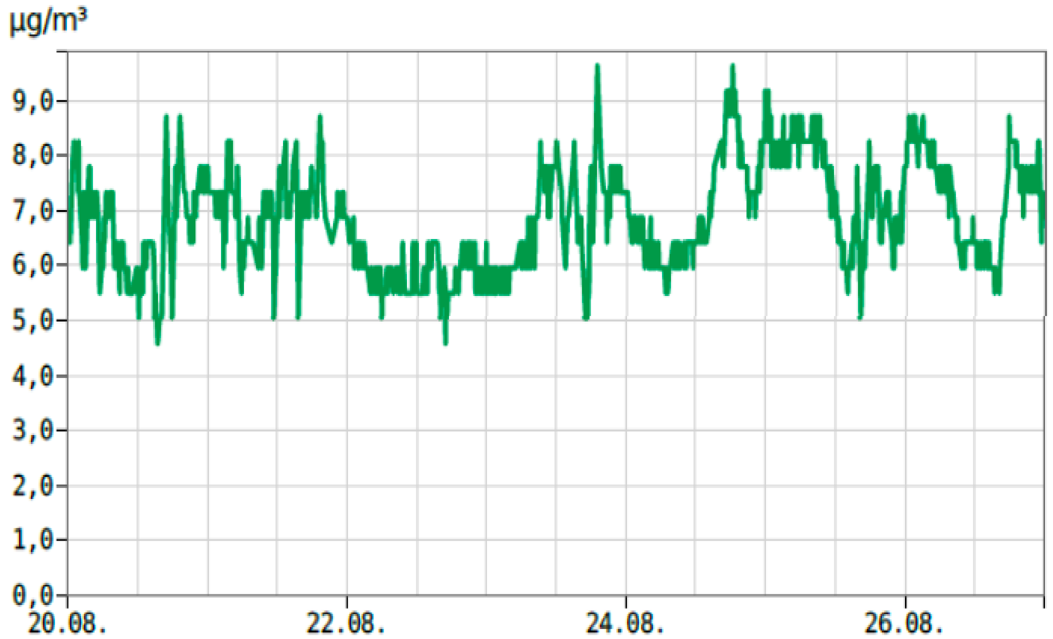


Figure 4.9 *Room 2 PM2.5 graph summary*

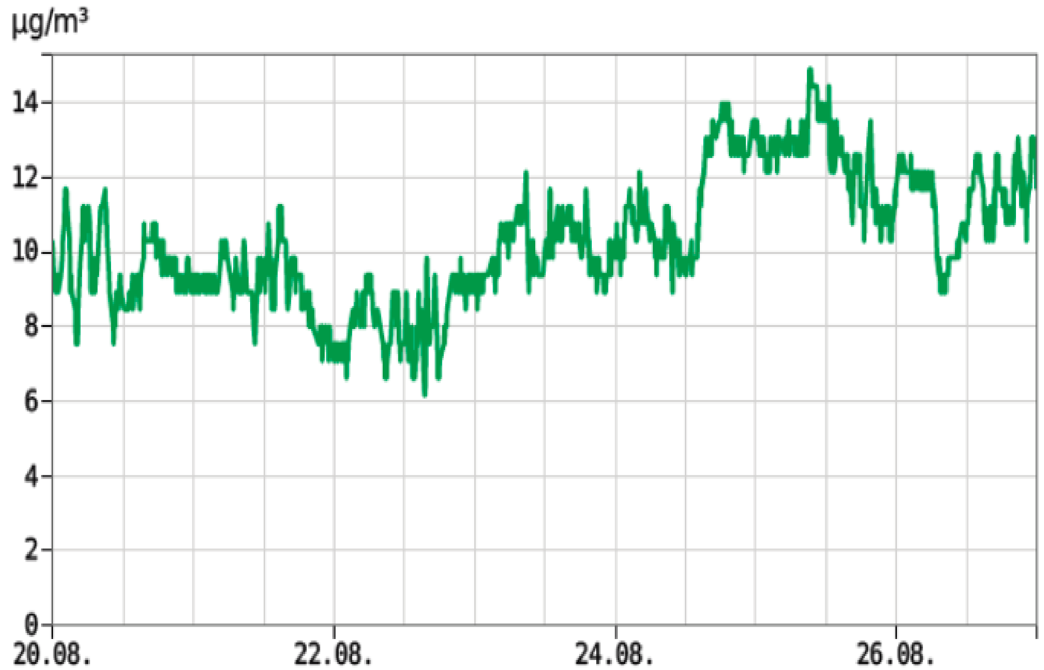


Figure 4.10 *Room 3 PM2.5 graph summary*

As we can see from the graphs that room 2 has no problem of particulate as the value hardly ever goes beyond 9. The average value remains at 7 which lies in the ideal parameters of particulate measurement.

Room 3 shows a varied result. The average value changes from day to day. The highest peak achieved around 14 which stays in that region throughout the working hours. It can be for any reason, maybe number of people increases tremendously.

Room 1 is the most surprising of all. It produces sharp peaks almost every day and then comes back to normal values. The reason can be any source. One reason could be that someone from the department brings particles with him/her every day.

It may, of course, be that with the purifier the PM2.5 level of the room 1 will decrease. Thus, there should be additional particle measurements with the purifier, for one week where operations would be like testing week. However, particle levels are probably not a major concern in the building most of the times.

Some extra actions that would be needed to deeply understand the sensor results.

- Measure the VOC and particle levels for one week with the purifier
- Measure VOC levels in the rooms using method of ISO 16000-6
- Measure most important VOC components
- Optimizing the sensors for different rooms
- Installation of optimal purifiers

4.3 Analysis of VOC and PM2.5 testing with relative humidity

Part 2 of the phase 2 included relative humidity along with VOC and PM2.5 sensors. The idea was to confirm the results taken in part 1 and compare it with relative humidity. Monitoring was done in the three different areas, same as in part 1 of this phase.

Even without a PM 2.5 purifier, the particle pollution levels are low. It can be concluded that the space does not need a particle purifier.

On the contrary, VOC levels rise to alarming levels at some spaces. They should be studied more precisely. The potential indoor VOC sources must be realized (emission usually occurring on Monday – Friday between 8:30-15:30), the measurement with a calibrated VOC monitor must be repeated and if still results get such high levels, it should be seen which specific VOCs there are in the rooms air. Only after that can the choice for which VOC filter to use can be made.

Average temperature of the lobby (room 1) was also taken during this phase. The results are as follows.

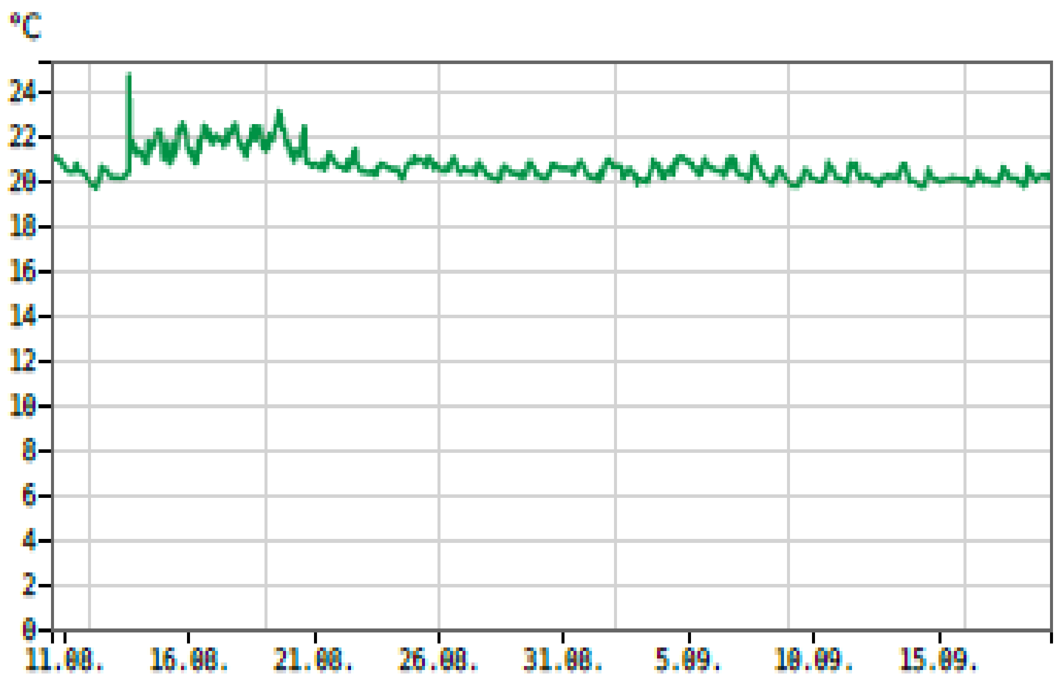


Figure 4.11 *Overall temperature during the testing phase2 part 2*

The temperature of all spaces remains constant and temperature fluctuations do not cause measurement errors.

Relative humidity of the monitored spaces is in common level. The fact that humidity changes in all spaces occur (approximately) at the same time hints that the changes are caused by RH changes in outdoor air and not by indoor sources. Graphs as below.

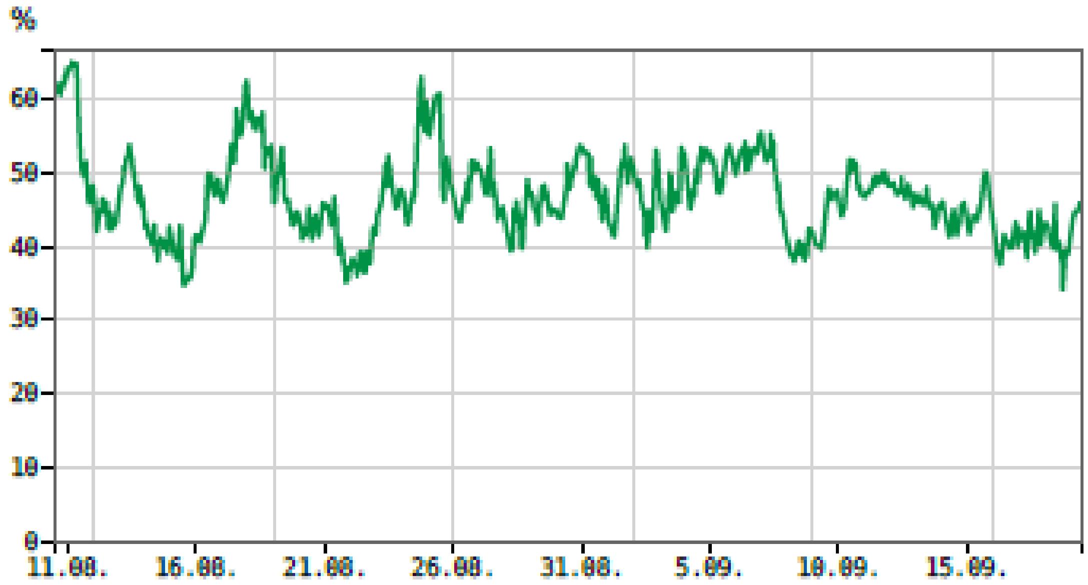


Figure 4.12 *Room 1 relative humidity graph summary*

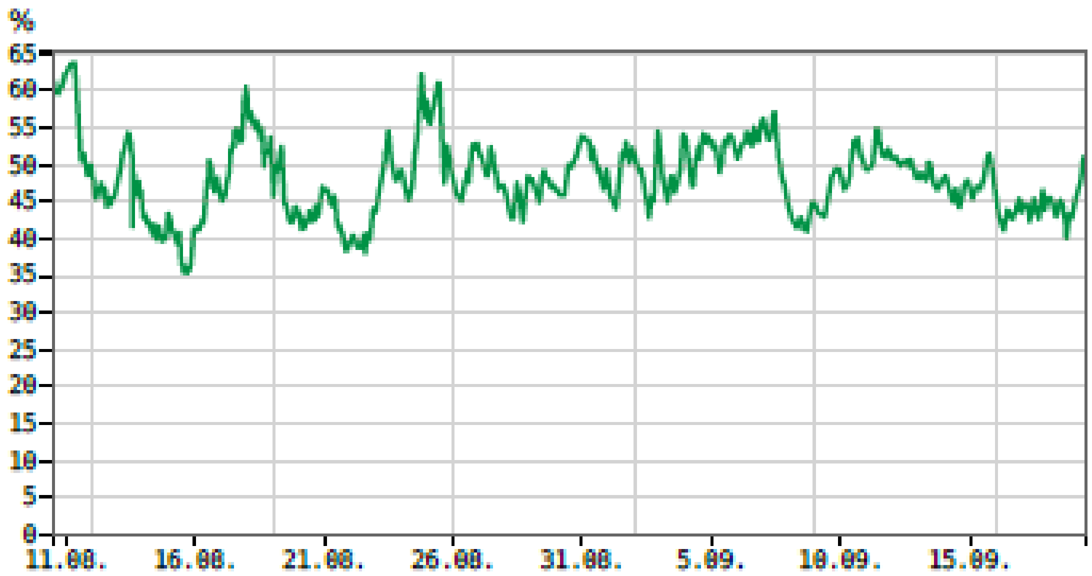


Figure 4.13 *Room 2 relative humidity graph summary*

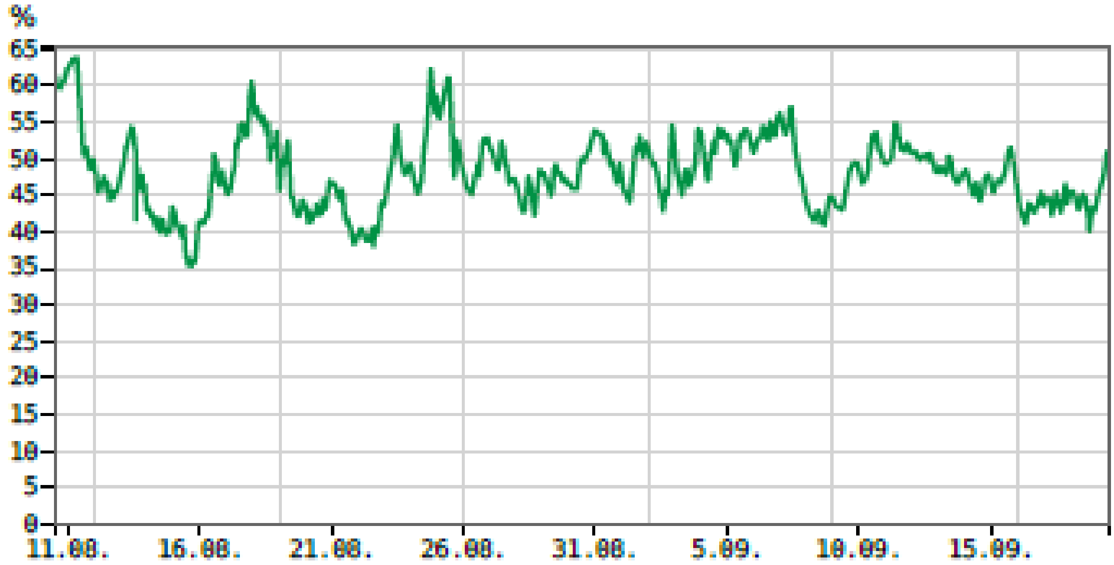


Figure 4.14 *Room 3 relative humidity graph summary*

Particle pollution levels without the purifier are low and there seems to be no need for $PM_{2.5}$ purifier in the space during normal use. The purifiers should, however, reduce the $PM_{2.5}$ levels. Thus, it should be checked, if the purifier will reduce the levels.

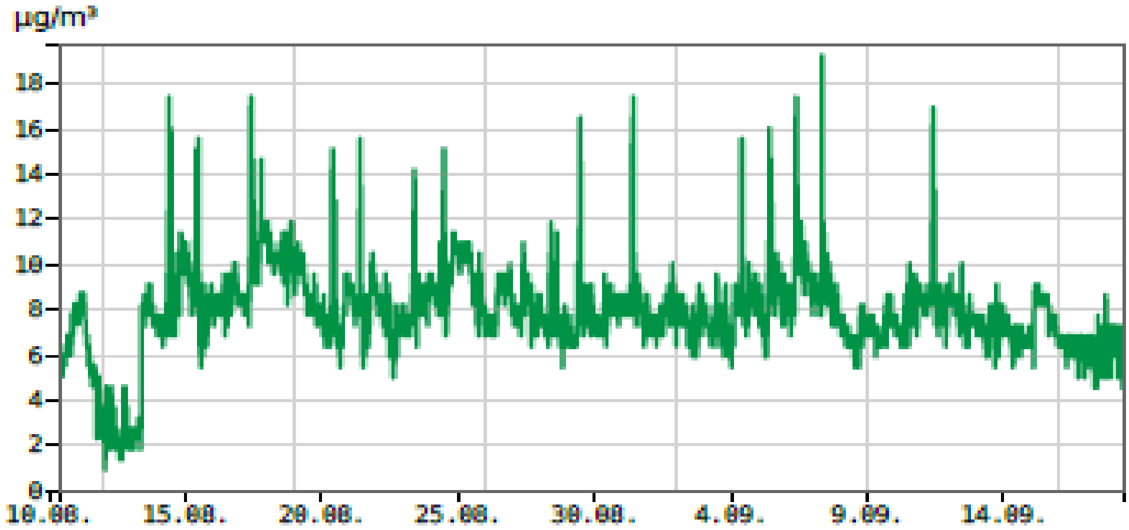


Figure 4.15 *Room 1 PM2.5 graph summary*

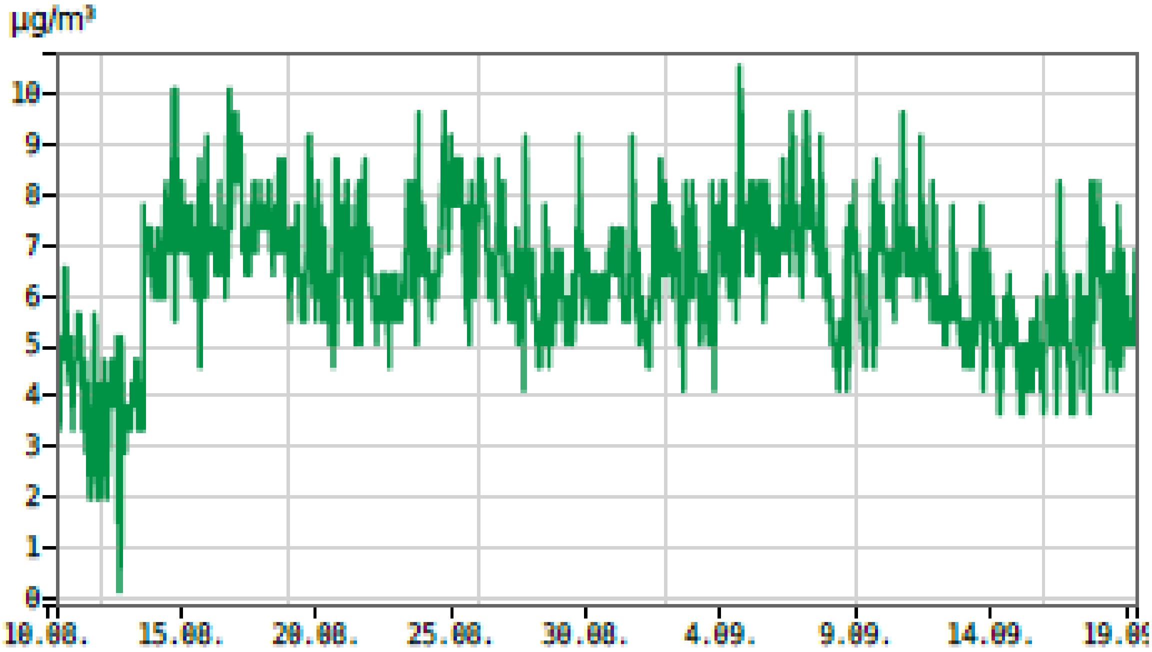


Figure 4.16 *Room 2 PM2.5 graph summary*

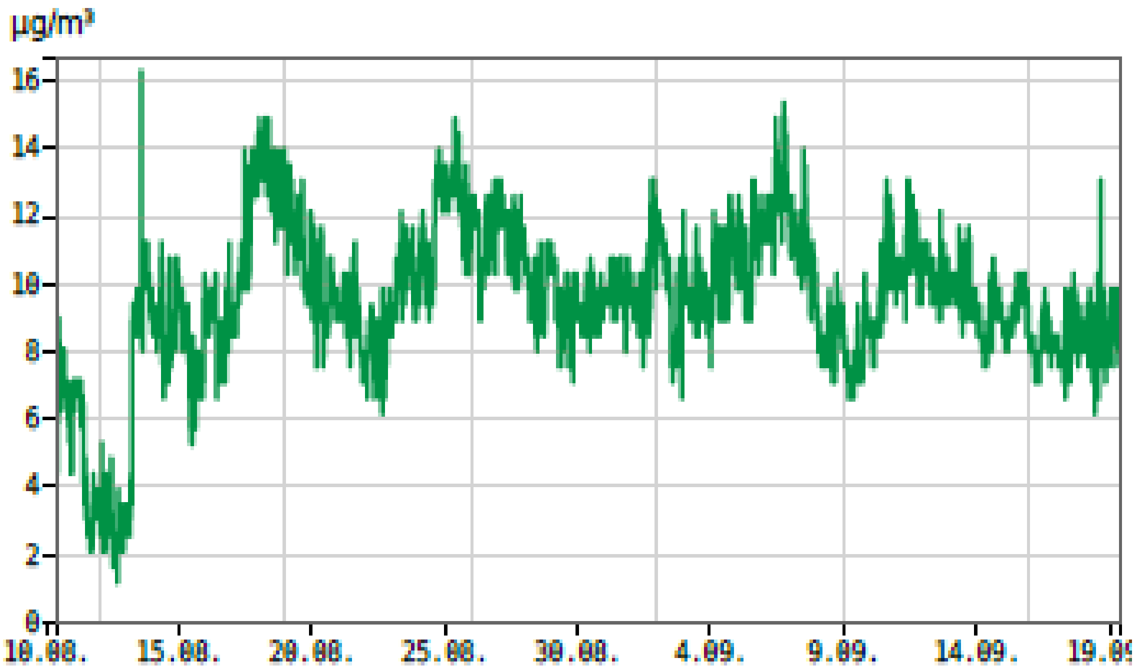


Figure 4.17 *Room 3 PM2.5 graph summary*

VOCs are a problem, marginal or larger at some spaces which contain indoor VOC emission source(s). As the VOC sensors are uncalibrated, the absolute values cannot be determined. They should be checked as Foobot sensor indicates VOC emission peaks. The VOC emission source(s) need to be found or VOCs analyzed in more detail to find out the VOS species which need to be purifies. Only after such examination can the decision on the optimal activated carbon filter for its purification can be taken.

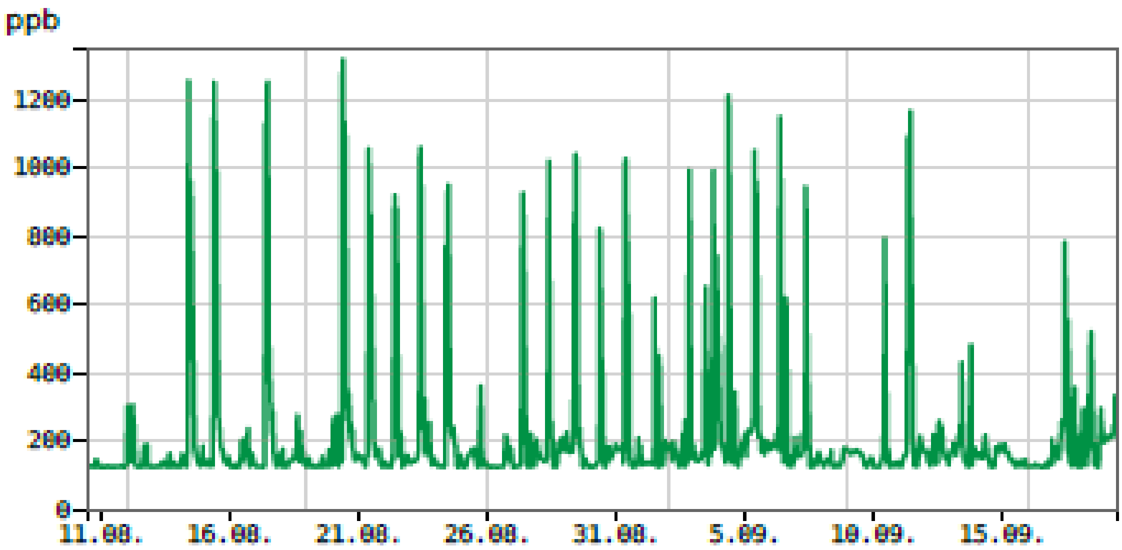


Figure 4.18 *Room 1 VOC graph summary*

Room 2:

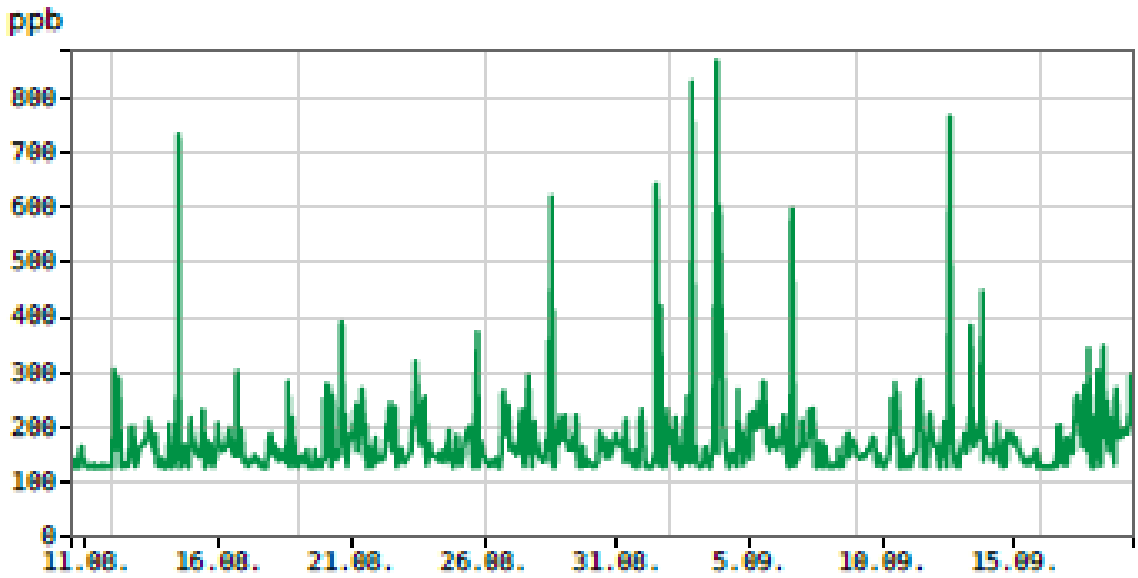


Figure 4.19 *Room 2 VOC graph summary*

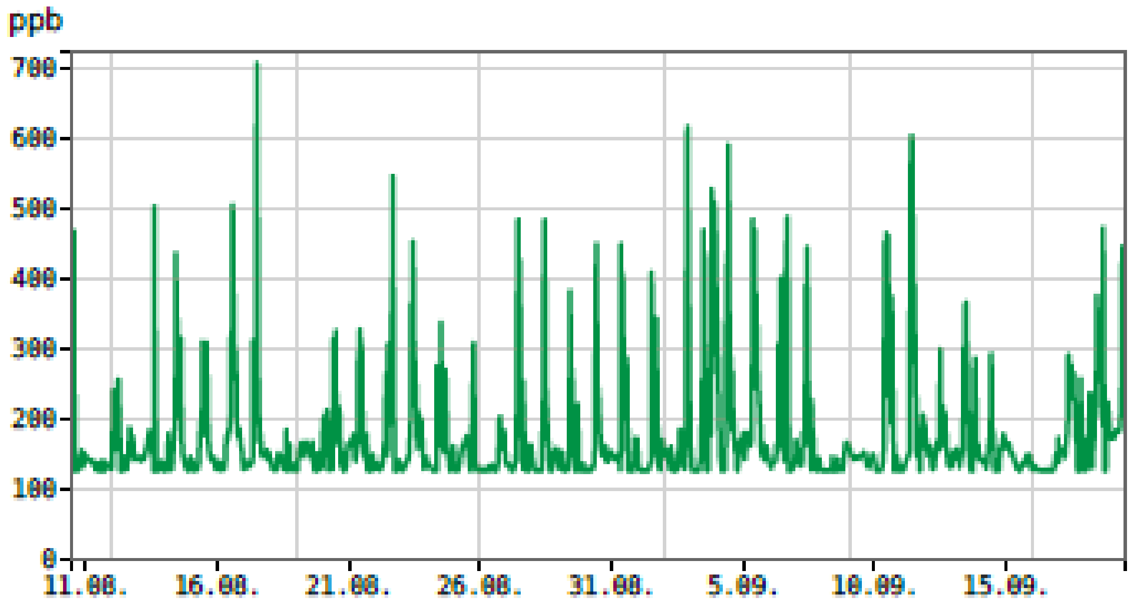


Figure 4.20 *Room 3 VOC graph summary*

4.4 Suggestions for the deeper testing results

Find out from the customer or an expert which kind of contaminant/pollutant is the customer worried about and what they would like to clean from the air. Best purifier should purify against particulate pollutants and VOCs which are equivalent to toluene. Most VOOCs are but e.g. removing formaldehyde (CH_2O) requires a different (impregnated) active carbon filter.

Make sure that the space is” limited”, i.e. the doors and windows are closed during the measurement period (i.e. most of the time). Make the user to keep a” look” where they mark everything what is done in the space. Ask the customer to keep the space closed. Of course, people must get in and out but doors should be closed after use and windows should not be opened.

Construct optimal purifier(s) for a trial period and test the purifier(s) in customer’s premises using a test pollutant ($PM_{2.5}$ or VOC).

Keep the purifier at minimum 60% power asking the customer not to switch it to a lower power if not totally necessary. Tell the customer that low power means poorer cleaning.

Record the pollutants for two weeks. Asking the customer to switch the purifier OFF after two weeks. Record the pollutants for the following week. Finally, analyze the results and write a report.

The pilot consists of six phases spanning over six months. At first, we will install all our sensors in the pilot cities and make sure they are working properly and connected to our cloud servers.

During second phase, we start collecting the data from our sensors and gather information from the people inside the pilot area. At the end of the second month we will form a report.

Next phase is about installing the purifier in the pilot area to reduce the air pollution. The most polluted space from each pilot area is picked through the previous collected data and install purifiers there.

Then collect and monitor the changes purifier has brought inside the premises and how much air pollution has reduced in the polluted space.

In the second last phase, switch off the purifier to check whether the purified space becomes polluted again when the purifier is switched off.

During all the phases, constantly take data from the users inside the department who are inside the pilot area.

At the end, analyze all the phases and make a report on how changes in indoor environment compared to the outdoors effected in people behavior.

Indicators are set for each phase and for everyone working in it.

1. Delays in data
2. Interruption caused by Wi-Fi
3. Time span when any sensor stops working
4. Accidental switching off any purifier or sensor by the users
5. Wrong installation by the workers
6. Accidental/un-accidental deletion of any data by backend engineers
7. Changing in travel timetable
8. Delay in reports by the manager
9. Sickness of any worker
10. Feedback of the users

These are all considered for the measurement of the overall quality of the project with last 7 also set as key indicators for the personal involved in the project.

During the pilot, we also have set key indicators for installation.

1. We need to make sure each sensor and purifier is installed at the perfect location inside the premises
2. For purifier, it must be inside the most polluted space
3. They should be working smoothly once installed throughout the phase
4. They must be sending data regularly without any interruption to our cloud

Following are the risks that can occur during the pilot phase due to various reasons:

1. Non-functioning of any installed sensor
2. Sensors switched off (Accidental)
3. Non-functioning of any purifier
4. Purifier switched off (accidental)
5. Wi-Fi problem
6. Problems at the cloud end
7. Sickness of any employee
8. Changes in travelling dates

Following are the ways risk can be management:

1. We have enough resources in number of sensors and purifiers. Every faulty sensor or purifier will be replaced or will be corrected as soon as possible
2. Our data center will immediately alarm if any sensor or purifier switches off
3. At the time of installation, we make sure the internet is available for the whole pilot phase
4. We have backup cloud server to gather data from the sensors
5. For every employee, we have a backup e.g. if project manager gets sick then project supervisor will complete his tasks
6. No one is working full time except project manager for this project, so in resource planning we have given enough time to complete the work even if someone gets sick
7. Whole month is given to installation of sensors and purifiers respectively. For each city installation, a week is added. Change of travel dates are accommodated in the plan as well

4.5 European market research for air quality

Solution described in previous section is an end to end solution approach including human interaction. In the current market, companies are either working in monitoring, purification or user interaction. No solution takes all three into consideration.

Solution includes portable and easy to install smart sensors, innovative purifiers and human interaction application that analyze human emotions through it.

Some Purifiers are fully customized and made with wood. As per the VTT test labs, analyzed purifier clean air delivery rate (CADR) is 1200 for the bigger purifier which is more than twice of any other purifier in the market. It can clean up to 120 sq. meters' space. With such high CADR, cleaning such a larger amount of space makes it unique and different from others.

Other purifiers removal of VOCs is based on conventional activated carbon is valid only for "toluene-equivalents", the purifier under consideration uses impregnated active carbon e.g. for formaldehyde removal.

Some purifier can be fully customized in terms of colors with the theme of the indoor space to make sure it looks like a piece of art and not a machine.

This kind of overall solution is not present in the current market and is ideal for hospitals, municipalities and hotels.

Cities across the world are now targeting to get carbon free inside next 30 years. More and more cities tend to get smarter and are looking for solutions to get rid of air pollution. Below are some of the cities who share the same intend and future goals.

By 2030 the city of Helsinki is targeting to decrease emissions by 60% and in the following five years it aims to neutralize carbon emission.

Eindhoven faces challenges in the field of sustainability and climate. They wish to adopt sustainable energy, and energy usage reduction. They want to specifically correlate sustainability to economic activity and employment in the city and region.

Antwerp city faces challenges in energy and environmental management. They aim to be climate-neutral by 2050 and looking for solutions in Environmental quality (air quality).

Mount Pearl aims to become smartest city in the region. They look to eliminate carbon emission and looking for innovative air quality and energy savings solutions through IOT. They have shown interest in the solution discussed.

4.5.1 Impacts of air quality on society

Air quality has become such an important agenda. It has wide range of impacts in a society that cannot be ignored. The impacts vary from economic to environmental and social. Each impact carries a lot of weightage.

Economic impacts are as follows:

1. Studies show better indoor air environment brings work optimization
2. Hotels and restaurant industry can attract more customers with better indoor environment
3. Cities indoor tourist spots can be less congested and fresher and healthy indoor environment will bring more tourists
4. Heating optimization helps to reduce indoor heating costs

Environmental impacts are as follows:

1. Most EU countries focus on climate and noise control, it is directly aligned with their interest
2. Indoor heating optimization air quality control brings energy savings and helps the environment to be under optimized level
3. Removing of dangerous particles, VOCs etc. reduces air pollution
4. Monitoring of noise helps the environment to tackle indoor noise pollution

Social impacts are as follows:

1. Cleaner air makes people breath healthy
2. Indoor environment system becomes smarter, so does the lifestyle of people working or living in those areas
3. The life style becomes healthier and it optimizes their energy potential by being less sick
4. People get more aware about their environment and they are always in control
5. People can register their emotions regularly through the app, hence they will know what kind of environment makes them happy or sad

Reasons for the indoor air quality to be taken seriously:

1. Hospitals are now gearing to become smart and looking to bring innovation
2. Most of the state hospitals in Europe are renovating and facing problem of indoor air quality specially VOCs
3. Most of the municipalities and state-owned places are old and have a problem of energy optimization and air quality, VOCs, mold and particles are major problems
4. Most of the indoor place owners are looking to reduce their cost of heating
5. Luxury hotels now intend to provide the most fresh and clean air to their customers, for which good quality and good-looking purifiers are necessary
6. Purifier makers who makes customized wooden purifiers as per the color scheme of the indoor place

Clients come from different industry segments. Indoor air and environment control is useful for almost every possible indoor place. The most common users we have are in the following categories:

1. Health industry specially Hospitals
2. Hotels
3. Municipalities
4. Companies offices
5. Embassies

5. CONCLUSIONS

The aim of this study was an effort towards finding innovative and portable solutions that can be infused in the air quality industry either presently or in the future. According to the world health organization indoor air pollution causes more harm to humans than any outdoor pollutant. There are many reasons of indoor air pollution and how it can affect us. Problem with human bodies is that they do not react until they don’t reach a certain limit. Our bodies tend to adjust to the surroundings we are in. Not many of us think about the quality of air we breathe, even though it has a direct connection to our lives and health. Before the limit is reached, our senses fail us and when our senses fail us we need something that can alarm us for the hazards around us. Once we get the alarm through an external source then we need an innovative air quality product to remove those impurities found in the surroundings.

To conduct this research, I wanted to understand the whole process of indoor air quality and not just one part of it. So, to study the whole process life cycle of indoor air quality, I divided the work into separate sections. During the whole process, the results indicate that indoor air pollution is growing and current market products still needs to work more on the portability and usability from the user point of view.

To tackle the current market situation. I attended many indoor air quality seminars, events and met various researchers. State of the art research papers were consulted to learn different research and solutions that are proposed or provided. State of the art research papers included “**Evaluating Health Impact of Air Pollution”**, “**Study on the purification effect of clean fresh air on PM2.5n the bedroom**” and “**Building user in terms of indoor air pollution exposure**” etc. These papers were published during the last year and covered many aspects of indoor environments. It provided me the knowledge and the insight of the work been done around the globe in this field.

After grasping the state-of-the-art research, market analysis of different product design and the surveys of different places was done to check how much need is currently available for monitoring and purification of air quality. Using the analysis, different marker products were chosen to conduct a gap analysis on them and proposals were given for the improvements that can be done in future versions.

Comparisons of the proposed solution with the other products in market was done in detail and explained how it is different and add value to the current solution or products in the market and to the users as well.

It was important to work on the proposed solutions myself, so I made a prototype of mobile application to see how the algorithms that I designed in the solution can be used to fetch indoor air quality data and turn it into some meaningful readings. For the prototype application, I used android studio.

The prototype considered six main variables presents in the air. The application could catch real time readings from the sensors for all the six variables. From real time data, it calculated real time graphs, current overall situation of the indoor premises and give tips to improve the situation.

The prototype was tested in the university indoor environment and the testing was done in two rounds. The idea was to accumulate indoor data alone during the first round and then do it again with the relative humidity sensor to understand the indoor climate with the changes happening to outdoor climate changes.

As the topic was wide and I choose to conduct an end to end research, the whole process took long. The importance of air quality is different in every continent. So, its advancements vary geographically as well. US and Nordics are growing market but southern Europe, Africa and Asia still behind in the eight-ball game. Africa lacks resources for the researches to be conducted in their premises and even though lots of research is done in Asia, the implementation part is still slow.

Application wise, the solutions proposed can be used in any indoor air monitoring or purification products. The idea was to understand different problems humans are facing and how the solution should be easy for the user to use it in its daily life. The solution tackles many industries and focuses on how different sectors and industries can use one portable product rather than many sensors or products.

The research carried out gives a way to understand the process life cycle of indoor air quality. It touches every step of the processes involved and gives light into how improvements can be made specially through digital means to make sure the usage of those solutions is easy to use for the user.

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